



**Australian Government**

**Australian Transport Safety Bureau**



**ATSB TRANSPORT SAFETY REPORT**  
Aviation Occurrence Investigation  
AO-2009-012  
Final

**Tailstrike and runway overrun  
Melbourne Airport, Victoria  
20 March 2009  
A6-ERG  
Airbus A340-541**





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Figure 9: Google Earth  
Figure 23: Lufthansa Systems Lido/RouteManual

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### Abstract

On the night of 20 March 2009, an Airbus A340-541, registered A6-ERG and operating as Emirates EK407, with 18 crew and 257 passengers, sustained a tailstrike and overran the end of the runway on departure from Melbourne Airport, Victoria. The investigation found that the accident resulted from the use of erroneous take-off performance parameters. Those erroneous parameters were themselves a result of an incorrect take-off weight being inadvertently entered into the electronic flight bag during the pre-departure preparation. Due to a number of factors, the incorrect data entry passed through the subsequent checks without detection.

As part of its investigation of the accident, the ATSB undertook a research study titled *Take-off performance calculation and entry errors: A global perspective* to review the factors involved in a number of incidents and accidents in the 20 years leading to 2009. That report indicated that this accident was just one of many occurrences involving the use of erroneous take-off performance parameters across a range of aircraft types, operators, locations and types of operation.

As in the accident under investigation, a consistent aspect of these occurrences was the apparent inability of flight crew to perform 'reasonableness checks' to determine when parameters were inappropriate for the flight. Equally significant was that degraded take-off performance was generally not detected by the flight crew until well into the take-off run, if at all. The investigation found that the take-off performance philosophy used in civil transport aircraft did not require the flight crew to monitor the acceleration of the aircraft or provide a reference acceleration that must be achieved.

As a result of the accident, the operator and aircraft manufacturer have taken, or are taking, a number of safety actions. In addition, the Australian Transport Safety Bureau (ATSB) has issued a safety recommendation to the United States Federal Aviation Administration and a safety advisory notice to the International Air Transport Association and the Flight Safety Foundation in an effort to minimise the likelihood of future similar events.

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# THE AUSTRALIAN TRANSPORT SAFETY BUREAU

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The Australian Transport Safety Bureau (ATSB) is an independent Commonwealth Government statutory agency. The Bureau is governed by a Commission and is entirely separate from transport regulators, policy makers and service providers. The ATSB's function is to improve safety and public confidence in the aviation, marine and rail modes of transport through excellence in: independent investigation of transport accidents and other safety occurrences; safety data recording, analysis and research; fostering safety awareness, knowledge and action.

The ATSB is responsible for investigating accidents and other transport safety matters involving civil aviation, marine and rail operations in Australia that fall within Commonwealth jurisdiction, as well as participating in overseas investigations involving Australian registered aircraft and ships. A primary concern is the safety of commercial transport, with particular regard to fare-paying passenger operations.

The ATSB performs its functions in accordance with the provisions of the *Transport Safety Investigation Act 2003* and Regulations and, where applicable, relevant international agreements.

## **Purpose of safety investigations**

The object of a safety investigation is to identify and reduce safety-related risk. ATSB investigations determine and communicate the safety factors related to the transport safety matter being investigated. The terms the ATSB uses to refer to key safety and risk concepts are set out in the next section: Terminology Used in this Report.

It is not a function of the ATSB to apportion blame or determine liability. At the same time, an investigation report must include factual material of sufficient weight to support the analysis and findings. At all times the ATSB endeavours to balance the use of material that could imply adverse comment with the need to properly explain what happened, and why, in a fair and unbiased manner.

## **Developing safety action**

Central to the ATSB's investigation of transport safety matters is the early identification of safety issues in the transport environment. The ATSB prefers to encourage the relevant organisation(s) to initiate proactive safety action that addresses safety issues. Nevertheless, the ATSB may use its power to make a formal safety recommendation either during or at the end of an investigation, depending on the level of risk associated with a safety issue and the extent of corrective action undertaken by the relevant organisation.

When safety recommendations are issued, they focus on clearly describing the safety issue of concern, rather than providing instructions or opinions on a preferred method of corrective action. As with equivalent overseas organisations, the ATSB has no power to enforce the implementation of its recommendations. It is a matter for the body to which an ATSB recommendation is directed to assess the costs and benefits of any particular means of addressing a safety issue.

When the ATSB issues a safety recommendation to a person, organisation or agency, they must provide a written response within 90 days. That response must indicate whether they accept the recommendation, any reasons for not accepting part or all of the recommendation, and details of any proposed safety action to give effect to the recommendation.

The ATSB can also issue safety advisory notices suggesting that an organisation or an industry sector consider a safety issue and take action where it believes appropriate, or to raise general awareness of important safety information in the industry. There is no requirement for a formal response to an advisory notice, although the ATSB will publish any response it receives.

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## EXECUTIVE SUMMARY

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On the night of 20 March 2009, the crew of an Airbus A340-541, registered A6-ERG were preparing the aircraft for a scheduled flight from Melbourne, Victoria to Dubai in the United Arab Emirates. The pre-departure preparation included the use of an electronic flight bag laptop computer (EFB) to calculate the performance parameters (take-off reference speeds, and flap and engine settings) for the takeoff from runway 16. That calculation relied on the manual entry into the EFB of several pieces of data, including the aircraft's take-off weight.

The take-off weight of the aircraft (361.9 tonnes) was available from the aircraft's flight management and guidance system (FMGS). The crew's intention was to take this figure, add a 1-tonne allowance for last-minute weight changes, and enter the result (362.9 tonnes) into the EFB.

When entering the take-off weight into the EFB, however, the first officer inadvertently entered 262.9 tonnes instead of the intended 362.9 tonnes and did not notice that error. The incorrect weight and the associated performance parameters were then transcribed onto the flight plan for later reference.

The EFB was handed to the captain to check the figures before he entered the calculated take-off performance parameters into the aircraft systems. There was a lot of activity in the cockpit at that time and it is likely that the associated distractions degraded the captain's checks, and the weight error remained undetected. The captain's checks also included a verbal check with the first officer that compared the take-off weight in the FMGS with the weight entered into the EFB for the take-off performance calculation. However, that verbal check was omitted, probably due to the various distractions and the pre-occupation of the first officer with confirming the departure clearance with air traffic control.

The captain entered the EFB performance figures into the FMGS and crosschecked them with the first officer against the previously-transcribed values on the flight plan.

There were two further opportunities to capture the error during the loadsheet confirmation procedure that was carried out by the flight crew immediately after the FMGS data entry crosscheck. The first opportunity was when the first officer read the take-off weight from the FMGS and then from the EFB take-off performance calculations on the flight plan. The first officer correctly read the weight from the FMGS as 361.9 tonnes but, when reading from the flight plan, he stated 326.9 tonnes before immediately 'correcting' himself to read 362.9 tonnes (the figure that included a 1-tonne allowance for last-minute changes). At the same point he 'corrected' the figure on the flight plan, thinking that he had made a simple transcription error when originally writing down the results from the EFB.

The second opportunity was at the end of the loadsheet confirmation procedure, when the first officer read out the green dot speed (a characteristic speed for the aircraft that was primarily determined by the aircraft's weight) from the FMGS. That speed was also calculated by the EFB, and was based on the take-off weight used in the calculation. The captain was required to record the green dot speed calculated by the EFB on his copy of the flight plan so this speed could be used as a gross error check of the performance calculation. When the first officer read out the green dot speed from the FMGS of 265 kts, the captain confirmed the figure, even though it was 40 kts greater than the EFB figure of 225 kts. The check was intended to ensure that the two figures were within

2 kts of each other but, because they both ended in a 5, the captain may not have noticed the difference in the values.

At this point, the flight was several minutes ahead of schedule and there were no time pressures affecting the flight crew. The flight crew completed the pre-departure preparation and the aircraft was pushed back from the terminal. The flight crew taxied the aircraft to the end of runway 16 for a southerly departure from runway 16.

The take-off run appeared to be normal until the captain called for the first officer, who was the pilot flying, to rotate the aircraft (that is, raise the nose so that the aircraft will lift off). When the first officer pulled back on the stick to raise the nose, the aircraft did not respond as expected. The captain again called rotate and the first officer pulled back further. The aircraft rotated but, as it was travelling too slowly to lift off, the rotation resulted in a tailstrike with significant damage to the underside of the fuselage. At about the same time, realising that 'something was not right', the captain commanded take-off go-around (TO/GA, or full) thrust from the engines, which responded immediately. The aircraft accelerated as it passed the end of the runway, along the stopway and across the grassed clearway. The aircraft became airborne in the clearway but struck a light and several antennae, which damaged and disabled the instrument landing system for the airport.

The flight crew climbed the aircraft to 7,000 ft and circled over Port Phillip Bay, Victoria, while jettisoning fuel to reduce the aircraft's weight. The flight crew then returned the aircraft to Melbourne for an uneventful landing on runway 34.

Although a number of contributing factors were identified, the ATSB determined that there were two primary factors in the development of the accident as follows:

- the flight crew did not detect the erroneous take-off weight that was used for the take-off performance calculations, and
- the flight crew did not detect the degraded take-off performance until very late in the take-off roll.

## **Erroneous take-off weight not detected**

It is commonly accepted that errors are possible when calculating take-off performance. As a result, flight crews are required to follow standard operating procedures that include the completion of various checks following that calculation. It was found that a number of human performance-related factors combined on the night to render the checks ineffective in this case. These factors included distraction and the effect of expectation when performing simple number comparisons.

The Australian Transport Safety Bureau (ATSB) noted that this accident was not an isolated event and that there had been numerous incidents and accidents related to erroneous take-off performance parameters prior to March 2009. The ATSB conducted a safety research study, titled *Take-off performance calculation and entry errors: A global perspective*, to review the factors involved in a number of incidents and accidents in the 20 years leading to 2009.

The ATSB research study, and a study carried out by the Laboratoire d'Anthropologie Appliquée (on behalf of the French investigation authority, the Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA)), each found that the manner in which performance calculation errors occurred varied and could involve any operator or

aircraft type. In common with this accident, they found that the flight crew did not detect the error or the reduced take-off performance until very late, if at all.

Both studies examined only those events that were investigated, or that were reported directly to the operator or investigation authority. The actual number of similar occurrences may have been greater during the 20-year period examined. Notwithstanding, the studies highlighted that serious take-off performance parameter-related events occurred at a rate of at least one per year. The most catastrophic of those events was the Boeing 747 freighter accident at Halifax, Canada, in 2004 that resulted in fatal injuries to all 7 crew members.

The ATSB found that, due to the large variation in take-off weights and performance parameters experienced by the flight crew during normal operations, the take-off performance parameter values were themselves not sufficient to alert the crew to a gross error situation. This inability to make a 'reasonableness' check of the performance parameters was also identified in the French study as applying to a much broader pilot group. With many pilots operating a range of transport aircraft in a mixed fleet flying environment, the range of parameters experienced is increasing and, without some guidance on how to manage the consequential loss of a 'reasonableness' check, this issue remains a significant problem for the worldwide fleet.

## **Degraded take-off performance not detected**

The flight crew of A6-ERG had planned for a reduced thrust takeoff in accordance with normal procedure. Once the erroneous performance parameters went undetected through the pre-flight checks, there was nothing to prevent the flight crew from attempting the takeoff using those figures. The use of the erroneous performance parameters meant that the calculated rotation speed was too low to provide sufficient lift for takeoff, resulting in the tailstrike, and that the thrust setting was too low, resulting in a degraded acceleration and subsequent runway overrun.

In this case, the aircraft did not attain a speed sufficient for lift-off within the length of the runway. If the captain had not applied full thrust, the take-off distance would have been even greater, and the consequences probably much worse.

The detection of degraded performance required both a measure of the actual acceleration, and an indication of the minimum acceleration required. The investigation found that the take-off performance philosophy used for civil transport aircraft did not require the acceleration to be monitored and as such, no information on the actual or required acceleration was provided to the flight crew. The only defence against degraded take-off performance was the flight crew and their ability to detect inadequate acceleration.

Without a specific method for comparing the actual acceleration to that required, flight crew must rely on comparing the 'feel' of the takeoff with their previous experiences. Because the reduced thrust takeoff optimises the takeoff for the local runway conditions and the aircraft's weight, the acceleration for the aircraft can vary with each takeoff. Due to the variations in runway conditions and weights experienced by flight crews in civil transport operations, that variation can be quite large, and not necessarily directly related to the aircraft's weight. Therefore, flight crews cannot reliably detect degraded performance until there is something more obvious, such as approaching the end of the runway without lifting off.

## **Safety action**

As a result of this accident, the operator and aircraft manufacturer have taken, or are taking, a number of safety actions. In addition, the ATSB has issued a safety recommendation to the United States Federal Aviation Administration and a safety advisory notice to the International Air Transport Association and the Flight Safety Foundation in an effort to minimise the likelihood of future similar events.

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# INVESTIGATION METHODOLOGY

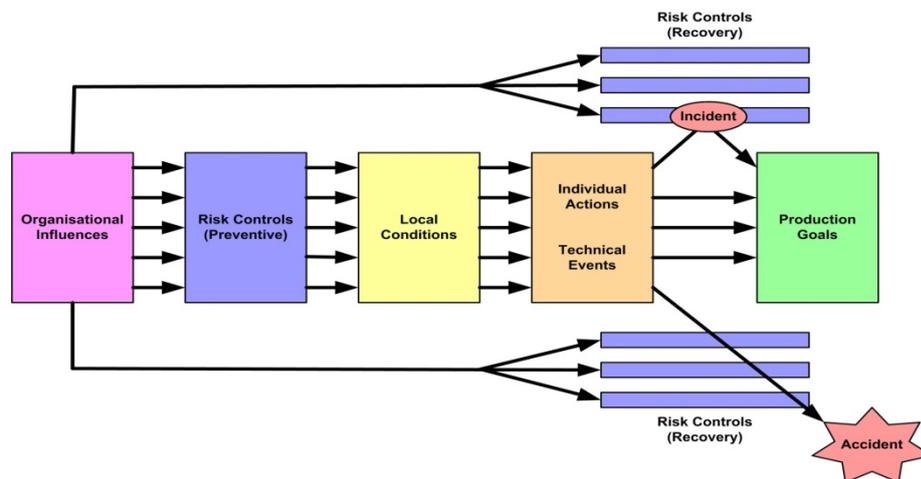
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An organisation achieves its production goals through a combination of events and conditions. Different organisations have different production goals, for example, the production goal for a transport operator is the transport of passengers and cargo from one location to another in a safe, efficient manner. In most situations, the production goals will be achieved; however, in some situations various events and conditions combine to produce an occurrence event where the system ‘goes off track’. If these events are not prevented by some form of control, an accident can result.

## The Australian Transport Safety Bureau model

The Australian Transport Safety Bureau (ATSB) has adapted the Reason Model<sup>1</sup> of accident causation. The ATSB model (Figure 1), shows the development of incidents (where an unsafe condition developed, but the risk controls returned it to the production goal) and accidents (where the risk controls were ineffective in recovering an unsafe condition).

**Figure 1: ATSB model for the development of an accident**



The ATSB model does not attempt to describe all of the complexities involved in the development of an accident, but attempts to provide a general framework to help guide data collection and analysis activities during an investigation.

For analysis purposes, the *ATSB model for the development of an accident* is represented as the *ATSB investigation analysis model* (Figure 2). The components of the model can be presented as a series of levels of potential safety factors.

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<sup>1</sup> Reason, J. (1990). *Human Error*. Cambridge University Press, Cambridge, United Kingdom.

**Figure 2: ATSB investigation analysis model**



From the investigation viewpoint, the most useful way of using the model to identify potential safety factors is to start from the occurrence events and work up to the organisational influences (the investigation path).

The five levels of factors in the ATSB investigation analysis model are defined as follows.

**Occurrence events** are the key events that describe the occurrence or ‘what happened’. Examples include technical failures, loss of aircraft control, breakdown of separation and overrunning the end of the runway.

**Individual actions** are observable behaviours performed by operational personnel. Such actions can describe how the occurrence events happened. It is widely acknowledged that people make errors every day and that flight crew are no exception. It is more productive to consider actions that increase risk (likelihood and/or level of consequences) as actions that should not occur in similar situations in the future, rather than failures of the individuals involved. Improvements in aviation safety will occur not by focusing solely on eliminating human error and violations, but by also ensuring there are adequate controls in place to ensure that when errors and violations do occur, they do not lead to an accident.

**Local conditions** are those conditions that exist in the immediate context or environment in which the individual actions or occurrence events occur, and which can have an influence on these actions and events. Local conditions can increase the likelihood of individual actions that increase safety risk. Examples include the nature of the task and the physical environment.

**Risk controls** are the measures put in place by an organisation to facilitate and assure the safe performance of operational personnel and equipment. The two main types of risk controls are preventive and recovery as follows:

Preventive risk controls are control measures implemented to minimise the likelihood and consequence of undesirable local conditions, individual actions and occurrence events. These controls facilitate and guide performance at the operational level to ensure that individual actions and technical events are conducted effectively, efficiently and safely. Such controls can include procedures, training, equipment design and fatigue risk management systems.

Recovery risk controls are control measures put in place to detect and correct, or otherwise minimise, the adverse effects of local conditions, individual actions and occurrence events. Such ‘last line’ controls include warning systems, emergency equipment and emergency procedures.

**Organisational influences** are those conditions that establish, maintain or otherwise influence the effectiveness of an organisation’s risk controls. There are two main types of organisational influences: internal organisational conditions and external influences. Those influences are defined as follows:

Internal organisational conditions are the safety management processes and other characteristics of an organisation which influence the effectiveness of its risk controls. Safety management processes include activities such as hazard identification, risk assessment, change management and monitoring of system performance.

External influences are the processes and characteristics of external organisations which influence the effectiveness of an organisation’s risk controls and organisational conditions. These influences can include the regulatory standards and surveillance provided by regulatory agencies. It also includes a range of standards and other influences provided by organisations such as industry associations and international standards organisations.

Although some of these factors are associated with the actions of individuals or organisations, it is essential to note that the key objective of a safety investigation is to identify safety issues – that is, the safety factors that can be corrected to enhance the safety of future operations. In accordance with the International Civil Aviation Organization (ICAO) *International Standards and Recommended Practices, Annex 13 to the Convention on International Civil Aviation, Aircraft Accident and Incident Investigation*; and the Australian *Transport Safety Investigation Act 2003*, the objective of accident and incident investigation is to prevent the occurrence of future accidents and not to apportion blame or liability.

Further information regarding the ATSB investigation and analysis methodology can be found in ATSB Aviation Research and Analysis Report AR-2007-053 *Analysis, Causality and Proof in Safety Investigations*, which is available at: <http://www.atsb.gov.au/publications/2008/ar2007053.aspx>.

## Findings

The result of the investigation and analysis is the identification of a set of occurrence findings. Those findings are listed in the Findings section of the report and are defined and categorised as follows:

**Safety factor:** an event or condition that increases safety risk. In other words, it is something that, if it occurred in the future, would increase the likelihood of an occurrence, and/or the severity of the adverse consequences associated with an occurrence. Safety factors include the occurrence events (for example, engine failure, signal passed at danger, grounding), individual actions (for example, errors and violations), local conditions, current risk controls and organisational influences.

**Contributing safety factor:** a safety factor that, had it not occurred or existed at the time of an occurrence, then either: (a) the occurrence would probably not have occurred; or (b) the adverse consequences associated with the occurrence would

probably not have occurred or have been as serious, or (c) another contributing safety factor would probably not have occurred or existed.

**Other safety factor:** a safety factor identified during an occurrence investigation which did not meet the definition of contributing safety factor but was still considered to be important to communicate in an investigation report in the interests of improved transport safety.

**Other key finding:** any finding, other than that associated with safety factors, considered important to include in an investigation report. Such findings may resolve ambiguity or controversy, describe possible scenarios or safety factors when firm safety factor findings were not able to be made, or note events or conditions which ‘saved the day’ or played an important role in reducing the risk associated with an occurrence.

**Safety issue:** a safety factor that (a) can reasonably be regarded as having the potential to adversely affect the safety of future operations, and (b) is a characteristic of an organisation or a system, rather than a characteristic of a specific individual, or characteristic of an operational environment at a specific point in time.

## Safety issue risk level and safety action

The ATSB’s assessment of the risk level associated with a safety issue is noted in the Findings section of the investigation report. It reflects the risk level at the time of the occurrence. That risk level may subsequently have been reduced as a result of safety actions taken by individuals or organisations during the course of an investigation.

Safety issues are broadly classified in terms of their level of risk as follows:

- **Critical** safety issue: associated with an intolerable level of risk and generally leading to the immediate issue of a safety recommendation unless corrective safety action has already been taken.
- **Significant** safety issue: associated with a risk level regarded as acceptable only if it is kept as low as reasonably practicable. The ATSB may issue a safety recommendation or a safety advisory notice if it assesses that further safety action may be practicable.
- **Minor** safety issue: associated with a broadly acceptable level of risk, although the ATSB may sometimes issue a safety advisory notice.

The steps taken, or proposed to be taken, by a person, organisation or agency in response to a safety issue is classified as a **safety action**. The safety actions reported to the ATSB at the time the report was published are presented in the Safety actions section of the report.

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# ABBREVIATIONS

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AAIB	Air Accident Investigation Branch (United Kingdom)
AC	Advisory Circular
ACARS	Airborne Communication Addressing and Reporting System
ACMS	Aircraft Condition Monitoring System
AKL	Auckland, New Zealand
ALS	Approach Lighting System
Alt	Altitude
AMJ	Advisory Material Joint
ARFF	Aviation Rescue and Fire Fighting
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
ATOW	Actual Takeoff Weight
ATSB	Australian Transport Safety Bureau
AZFW	Actual Zero Fuel Weight
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
BLT	Boeing Laptop Tool
CAAP	Civil Aviation Advisory Publication
CAR	Civil Aviation Regulation
CAS	Computed Air Speed
CAVOK	Ceiling and Visibility and weather OK
CCQ	Cross Crew Qualification
CD	Compact Disc
CG	Centre of Gravity
CL	Climb Thrust
CONF	Configuration
CS	Certification Specifications
CVR	Cockpit Voice Recorder
DAR	Digital ACMS Recorder
DFDR	Digital Flight Data Recorder
DGAC	Direction générale de l'Aviation civile
DOI	Dry Operating Index
DOW	Dry Operating Weight
DXB	Dubai, United Arab Emirates
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference

ECAM	Electronic Centralised Aircraft Monitor
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instrument System
EPR	Engine Pressure Ratio
FAA	(United States) Federal Aviation Administration
FADEC	Full Authority Digital Engine Control
FAST	Fatigue Avoidance Scheduling Tool
FCOM	Flight Crew Operating Manual
FCTM	Flight Crew Training Manual
FCU	Flight Control Unit
FDR	Flight Data Recorder
FLEX	Flexible (takeoff)
FLTOW	Flex Limiting Takeoff Weight
FLX/MCT	FLEX/Maximum Continuous Thrust
FMC	Flight Management Computer
FMGC	Flight Management and Guidance Computer
FMGS	Flight Management and Guidance System
FMS	Flight Management System
FOM	Flight Operations Manual
FRMS	Fatigue Risk Management System
ft	Feet
GCAA	General Civil Aviation Authority
GW	Gross Weight
GWCG	Gross Weight Centre of Gravity
HF	High Frequency
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
INIT B	MCDU Initialisation page B
JAA	Joint Aviation Authorities
JAR	Joint Airworthiness Regulations
JOEB	Joint Operation Evaluation Board
kg	Kilogram
kN	Kilonewton
kts	Knots
LAA	Laboratoire d'Anthropologie Appliquée
LAW	Landing Weight
LPC	Less Paper Cockpit
m	Metres

M	Magnetic
MAC	Mean Aerodynamic Chord
MCDU	Multi-purpose Control and Display Unit
MEL	Melbourne, Australia
MFF	Mixed Fleet Flying
MTOW	Maximum Take-off Weight
NASA	National Aeronautics and Space Agency
NLR	Dutch National Aerospace Laboratory
NTSB	National Transportation Safety Board (United States)
OPT CONF	Optimum Configuration
PDC	Pre-departure Clearance
PERF	MCDU Performance Page
PF	Pilot Flying
PFD	Primary Flight Display
PIC	Pilot in Command
PNF	Pilot not flying
POB	Persons on Board
QRH	Quick Reference Handbook
SAE	Society of Automotive Engineers
SFS	Senior Flight Steward
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
TC	Transport Canada
THS	Trimmable Horizontal Stabiliser
TODC	Take-off Data Calculation
TO/GA	Take-off / Go-around
TOPMS	Take-off Performance Monitoring System
TOS	Take-Off Securing Function
TOW	Take-off Weight
TSB	Transport Safety Board (Canada)
UAE	United Arab Emirates
ULR	Ultra Long Range
UTC	Coordinated Universal Time
V <sub>1</sub>	Decision Speed
V <sub>2</sub>	Take-off Safety Speed
VHF	Very High Frequency
V <sub>LOF</sub>	Lift-off Speed
V <sub>MU</sub>	Minimum Unstick Speed

$V_R$	Rotation Speed
ZFW	Zero Fuel Weight
ZFWCG	Zero Fuel Weight Centre of Gravity



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# 1 FACTUAL INFORMATION: GENERAL

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## 1.1 History of the flight

On the night of Friday 20 March 2009, 257 passengers, 14 cabin crew and 4 flight crew<sup>1</sup> boarded an Airbus A340-541, registered A6-ERG, for a scheduled passenger flight from Melbourne, Victoria, to Dubai, United Arab Emirates (UAE). The flight, operating as Emirates flight EK407, was scheduled to depart Melbourne at 2225 Australian Eastern Daylight-saving Time<sup>2</sup> and had a planned flight time of 14 hours and 8 minutes.

The pre-departure preparation included the use of an electronic flight bag (EFB) laptop computer to calculate the performance parameters for the takeoff from runway 16 (see section 2.3.7 *Obtaining take-off performance data from the EFB*). The EFB calculation required the input of a range of data: wind speed and direction; outside air temperature; altimeter setting; take-off weight; flap configuration; air conditioning status; anti-ice selection; runway surface condition; and aircraft centre of gravity.

A base take-off weight figure (361.9 tonnes) was taken from data in the aircraft's flight management and guidance system (FMGS)<sup>3</sup>. An additional tonne was added to that figure to allow for any minor last-minute changes in weight, making a total figure of 362.9 tonnes. When entering that take-off weight into the EFB, however, the first officer inadvertently entered 262.9 tonnes instead of 362.9 tonnes and did not notice that error.

Based on the weight and other input information, the EFB calculated take-off performance parameters (including reference speeds and engine power settings) for entry into the aircraft's flight systems. The incorrect weight and the associated performance parameters were then transcribed onto the master flight plan<sup>4</sup> for later reference. At about this time, the captain and first officer discussed an aspect of the standard instrument departure that appeared to cause some confusion between the flight crew.

The EFB was handed to the captain to check the performance figures before he entered them into the aircraft systems. While the captain was checking the figures entered into the laptop, the first officer was confirming the departure clearance with

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<sup>1</sup> The duration of the flight meant that an augmenting flight crew (captain and first officer) had to be carried to provide the operating flight crew with rest breaks during the flight.

<sup>2</sup> Unless otherwise annotated, the 24-hour clock is used in this report to describe the local time of day, Australian Eastern Daylight-saving Time, as particular events occurred. Australian Eastern Daylight-saving Time is Universal Coordinated Time (UTC) + 11 hours.

<sup>3</sup> An aircraft computer system that contained data used by the aircraft to guide it along a pre-planned route, altitude, and speed profile (see Appendix B.8).

<sup>4</sup> A document produced by the operator that contained information on the planned flight route and estimates of the weights, flight times and fuel requirements. The flight crew obtained the flight plan from station personnel on arrival at the airport as part of a flight documentation package. The package contained several copies of the flight plan. During the pre-departure preparation, the first officer was responsible for the 'Master' copy of the flight plan.

air traffic control. There were also activities taking place that involved other persons in the cockpit and forward galley area.

The captain's checks were required to include a verbal check between the captain and first officer to compare the take-off weight in the FMGS with that used in the take-off performance calculation. That verbal check did not take place in this instance.

The captain entered the EFB performance figures into the FMGS and crosschecked them with the first officer against the values that were previously transcribed onto the flight plan.

The captain handed the EFB back to the first officer, who stowed the EFB before they both completed the loadsheet confirmation procedure. During that procedure, the first officer correctly read the weight from the FMGS as 361.9 tonnes but, when reading from the flight plan, stated 326.9 tonnes before immediately 'correcting' himself to read 362.9 tonnes (the amended figure that included a 1 tonne allowance for last minute changes). Among the other checks in the loadsheet confirmation procedure, the first officer read out the green dot speed<sup>5</sup> of 265 kts from the FMGS. The captain accepted that speed and the procedure was completed.

The flight crew completed the pre-departure preparation and at 2218:28, the aircraft was pushed back from the terminal 7 minutes ahead of schedule and was taxied to the northern end of runway 16 for takeoff. At 2230:46, ATC cleared the aircraft to line up and then cleared it for takeoff in front of an aircraft that was on final approach. The thrust levers were set to the take-off position and the aircraft accelerated along the runway.

At 2231:53, when the aircraft had reached the calculated rotation speed, the captain called 'rotate'. The first officer, who was the pilot flying, applied a back-stick (nose up) command to the sidestick, but the nose of the aircraft did not rise as expected. The captain again called 'rotate' and the first officer applied a greater back-stick command. The nose began to rise, but the aircraft did not lift off from the runway. The captain selected take-off / go-around (TO/GA) thrust on the thrust levers. The engines responded immediately, and the aircraft accelerated as it passed off the end of the runway, along the stopway<sup>6</sup> and across the grassed clearway<sup>7</sup>. The aircraft became airborne 3 seconds after the selection of TO/GA but, before gaining altitude, it struck a runway 34 lead-in sequence strobe light and several antennae, which disabled the airport's instrument landing system for runway 16.

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<sup>5</sup> The aircraft's best lift to drag ratio speed in the clean configuration (flaps and landing gear retracted). The speed is affected by aircraft weight and altitude only.

<sup>6</sup> 'A defined rectangular area on the ground at the end of take-off run available prepared as a suitable area in which an aircraft could be stopped in the case of an abandoned take off.' (International Civil Aviation Organization (ICAO) Annex 14, *Aerodromes*, Volume 1, *Aerodrome and Operations*, 5<sup>th</sup> edition, July 2009).

<sup>7</sup> 'A defined rectangular area on the ground or water under the control of the appropriate authority, selected or prepared as a suitable area over which an aeroplane may make a portion of its initial climb to a specified height.' (ICAO Annex 14, *Aerodromes*, Volume 1, *Aerodrome and Operations*, 5<sup>th</sup> edition, July 2009). A clearway must be free of obstacles that protrude above the level of the runway end.

Shortly after, the crew were alerted to a tailstrike by an automated message in the cockpit and a radio call from air traffic control (ATC). The crew decided to return to Melbourne to assess the damage.

After stabilising the aircraft in a normal climb, the captain informed ATC of the intention to climb to 5,000 ft and the need to jettison fuel prior to returning for landing. ATC cleared the crew to climb to 7,000 ft and radar vectored them over water to facilitate the fuel jettison.

At 2237, about 5 minutes after lift-off, the crew commenced planning for the approach and landing. The first officer retrieved the EFB from its stowage to carry out the landing performance calculations and determine a suitable landing weight. The EFB was still in the take-off performance module and the crew noticed that the weight used for the take-off calculations was about 100 tonnes below the aircraft's actual take-off weight.

At 2239, while climbing to 7,000 ft, the augmenting first officer informed the flight crew that the aircraft was not pressurising. The captain asked the augmenting first officer to locate the procedures for action in the event of a tailstrike in the aircraft's operational documentation. After reviewing the documentation, the augmenting first officer informed the captain that he was unable find the procedure for a tailstrike.<sup>8</sup>

At 2246, the captain contacted ATC and declared a PAN.<sup>9</sup> All four flight crew then discussed an appropriate landing weight and decided to jettison fuel for a landing weight of 280 tonnes. Although above the aircraft's maximum landing weight, the crew chose 280 tonnes as a precaution in case several approaches were required. To ensure that there were no further performance calculation errors, the flight crew made three independent calculations of the landing performance using two different references - the EFB and the quick reference handbook (QRH).

At 2311, ATC informed the crew of debris and runway surface damage found during an inspection of the runway and surrounding area. Later, ATC updated the crew on the damage, informing them that the operator's ground engineers had inspected some of the items retrieved and that they should expect 'significant damage to the tail'.

During the flight, the flight crew communicated with the cabin crew primarily via the intercom system, although the purser was provided with a detailed briefing in the cockpit. Communication was predominantly with the purser; however, the captain also contacted the senior flight steward in the rear of the cabin to ask about the cabin crew's observations during the takeoff.

The captain gave the passengers two briefings over the passenger address system. The briefings included basic information on the situation and advice on the fuel jettison.<sup>10</sup> and return to Melbourne.

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<sup>8</sup> The operator's *Flight Crew Operating Manual* did contain a procedure in the case of a tailstrike. The procedure specified that in the event of a tailstrike warning, the flight crew were to limit flight to 10,000 ft to minimise the stress on the airframe and return to an airport for damage assessment as soon as possible.

<sup>9</sup> International radiotelephony signal for an *urgency* condition.

<sup>10</sup> The nozzles for the fuel jettison system were located at the trailing edge of the wings and were visible to passengers in the cabin.

On completion of the fuel jettison, the flight crew prepared for the approach and commenced a descent from 7,000 ft to 5,000 ft. At 2327, as they were passing through about 6,500 ft and slowing the aircraft, the captain heard an unusual rumbling sound. The sound was unexpected and caused a degree of concern among the flight crew. Moments later, the senior flight steward at the left rear door contacted the flight crew to advise that he could see and smell smoke in the rear cabin. The first officer contacted ATC, informing them of smoke in the cabin and requested clearance for an immediate approach. ATC cleared the flight crew to descend to 3,000 ft and, subsequently, for the approach to runway 34. The first officer briefed the purser on the possibility of an evacuation after landing.

At 2332, the crew changed to the Melbourne Tower radio frequency. At the request of the flight crew, the Melbourne Tower controller organised for the aviation rescue and fire fighting (ARFF) vehicles to be on the tower frequency to allow direct communication with the flight crew. As there were several ARFF vehicles involved, there was a significant amount of radio communication between ATC and ARFF vehicles during the latter stages of the approach. The first officer reported that the additional radio communication resulted in some distraction.

At 2336:29, 1 hour and 4 minutes after lift-off, the aircraft touched down on runway 34 and rolled to the end of the runway where it was met by the ARFF services vehicles. After the aircraft came to a stop on the runway, the captain made an announcement for the cabin crew to prepare for a possible evacuation.

The aircraft was briefly inspected by the ARFF services personnel for signs of smoke and fire. None were evident and the flight crew were cleared by ATC to taxi the aircraft to the terminal. The captain advised the cabin crew to revert to normal operations and taxied the aircraft back to the terminal where the passengers disembarked.

There were no injuries to the passengers or crew.

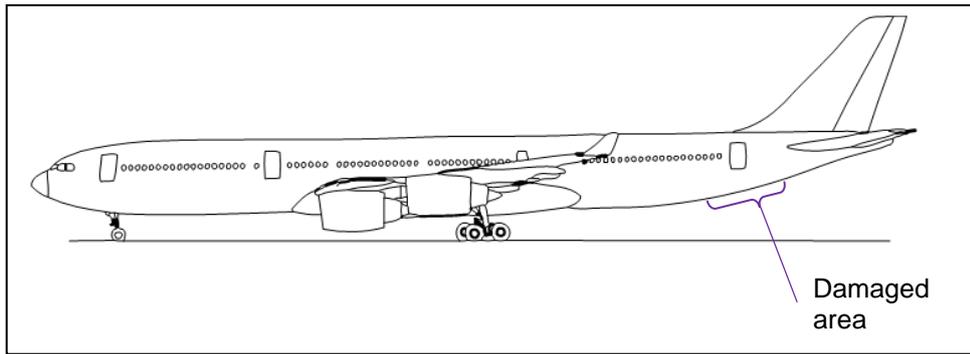
## 1.2 Damage to the aircraft

Inspection of the aircraft revealed serious damage<sup>11</sup> to the underside of the rear fuselage (Figure 1), where the lower skin panels were abraded by contact with the runway surface (Figure 2). In some areas, the skin was worn through its full thickness and grass and soil was caught in the airframe structure (Figure 3). A service panel was dislodged and was found beyond the end of runway 16 (Figure 3), along with numerous pieces of metal from the abraded skin panels.

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<sup>11</sup> Based on the damage to the aircraft, the Australian Transport Safety Bureau classified this event as an accident. Consistent with the ICAO definition outlined in Annex 13 to the Chicago Convention, an accident is defined in the *Transport Safety Investigation Act 2003* as an investigable matter involving a transport vehicle where the vehicle is destroyed or seriously damaged.

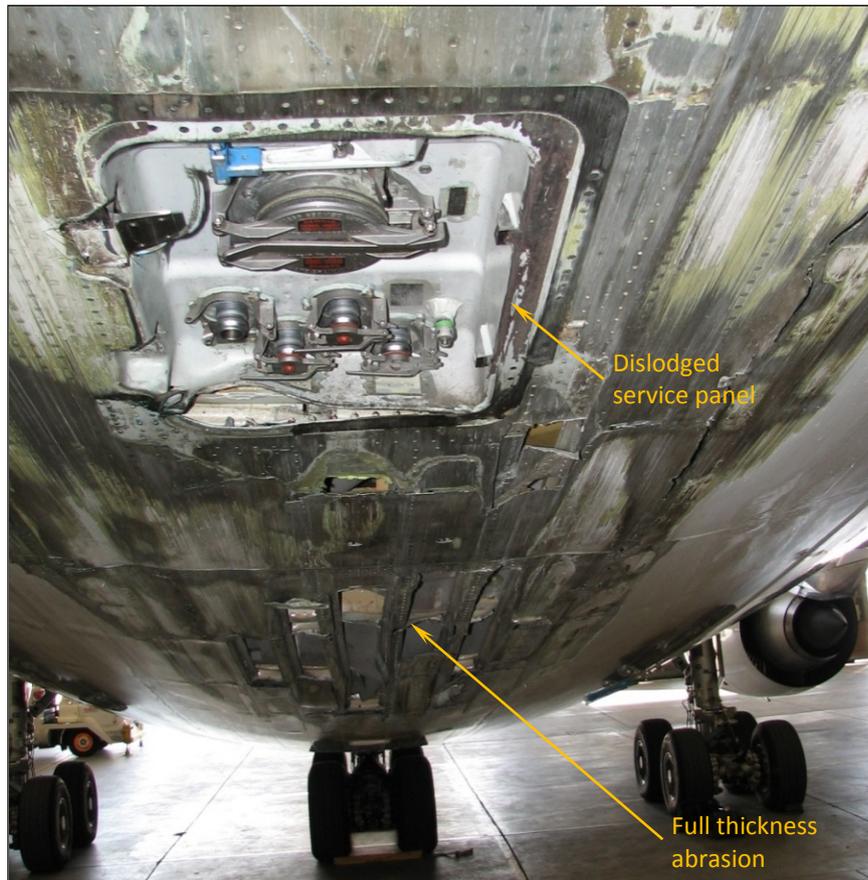
**Figure 1: Location of damage**



**Figure 2: Skin abrasion**



**Figure 3: Skin abrasion detail**



The right side rear fuselage contained several contact marks. One contact mark, forward of the abraded area and immediately below the rear cargo door (Figure 4), was orange in colour consistent with the orange paint on the localiser near-field monitor antenna. Another contact mark was located adjacent to the skin abrasion and consisted of several fine, divergent marks running rearwards and slightly upwards (Figure 5).

**Figure 4: Contact mark below rear cargo door**

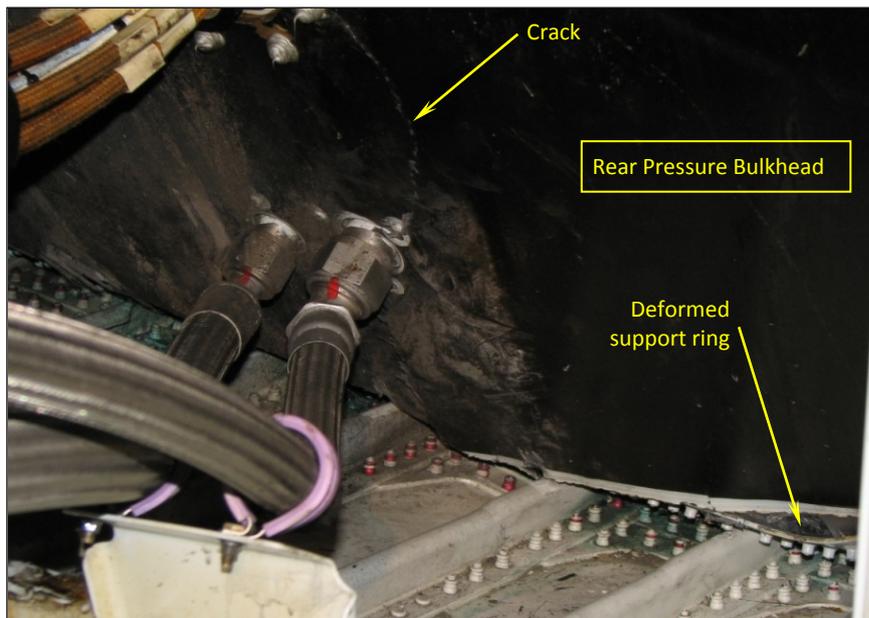


**Figure 5: Contact marks adjacent to the skin abrasion**



Numerous fuselage frames and stringers in the rear fuselage area were damaged by the abrasion and contact forces during the tailstrike. The damaged frames were deformed and several were cracked. The composite rear pressure bulkhead<sup>12</sup> had cracked, and the bulkhead diaphragm support ring was deformed (Figure 6).

**Figure 6: Example of rear pressure bulkhead damage**



The inboard rear tyre on the left main landing gear had a scuff mark on its sidewall (Figure 7). The mark contained transferred material that was the same orange colour as the localiser antenna system.

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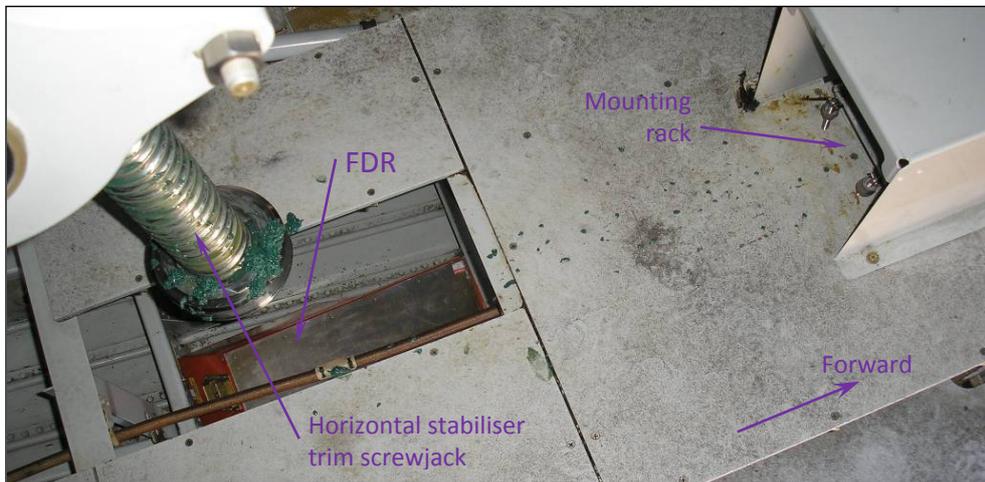
<sup>12</sup> An airtight diaphragm that forms the rear pressure wall of the cabin.

**Figure 7: Contact mark on the left main landing gear, inboard rear tyre**



The flight data recorder (FDR) was dislodged from its mounting rack immediately behind the rear pressure bulkhead and was found lying on the lower fuselage skin below and slightly to the rear of the mounting rack (Figure 8). The FDR was undamaged and contained recorded data from the commencement of the take-off roll until the dislodgement at 2232:05. The results of an examination of the FDR rack are at Appendix A.

**Figure 8: Location of the dislodged FDR and its mounting rack**



### 1.3 Other damage

An inspection of the runway, stopway, clearway, and overrun areas identified multiple contact marks, consistent with the tailstrike and overrun (Figure 9). The aircraft's tail contacted the runway at three locations, starting at 265 m, 173 m, and 110 m from the end of the runway, respectively (indicated by ①, ②, and ③ in

Figure 9). The contact marks contained white paint and metallic material, consistent with the construction and paint scheme of the underside of the aircraft.

There was a small drop-off at the end of the stopway that resulted in the fuselage losing contact with the ground until point ④ in the clearway (Figure 9), 67 m beyond the end of the runway. The final ground contact mark ended 148 m beyond the end of the runway (position ⑤ in Figure 9).

Typical contact marks on the runway and grassed area beyond the runway end are shown in Figure 10.

Figure 9: Ground contact marks



**Figure 10: Typical contact marks on runway, stopway and grassed areas**



To the south of the last ground contact mark, the fuselage contacted the runway 34 lead-in strobe light that was closest to the runway 16 end (Figure 11). That contact was slight and resulted in scrape marks on the support post and slight deformation of the lens shield. A small strip of white paint was located adjacent to the strobe light (Figure 11).

**Figure 11: Lead-in strobe light**



The aircraft struck the runway 16 localiser near-field monitor antenna and the main localiser antenna array. The localiser near-field monitor antenna support post was fractured at the base and fell in the approximate direction of takeoff (Figure 12). The antenna was damaged and the top of the support post was indented and exhibited white paint transfer.

**Figure 12: Localiser near-field monitor antenna**



View looking along direction of takeoff, away from the runway

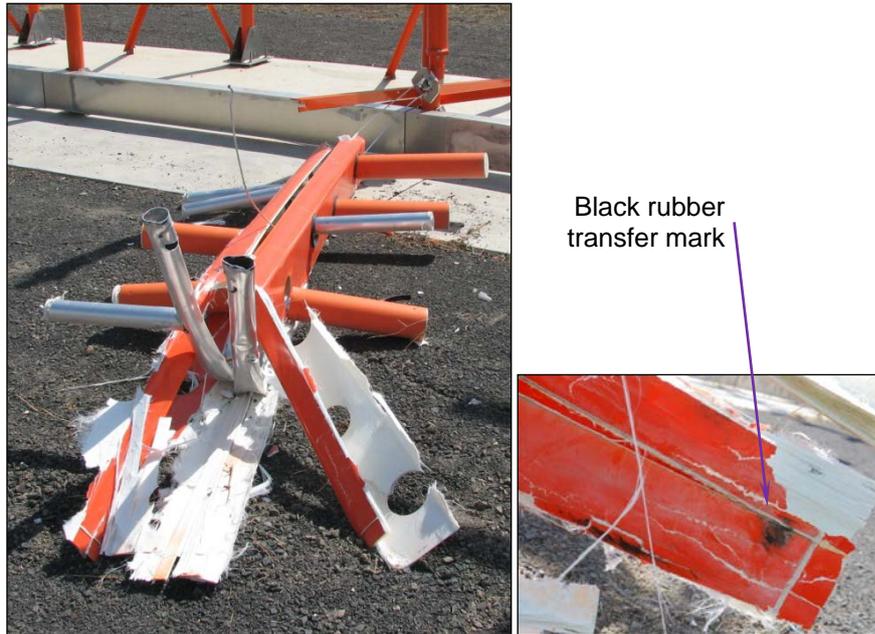
Damage to the localiser antenna array was limited to one of the 16 antennae (Figure 13). The forward (runway) end of the damaged antenna was deformed and the composite cover was severely disrupted. The top of the forward end of the antenna had a black, rubber-like marking and the deformation of the antenna was consistent with an impact (Figure 14).

**Figure 13: Localiser antenna array**



View looking along direction of takeoff, away from the runway

**Figure 14: Damaged localiser antennae**



View looking north, towards the runway

## 1.4 Personnel information

### 1.4.1 Operating flight crew

#### ***Captain***

The captain was rated on the Airbus A330-243, A340-313K and A340-541. In the preceding 90 days, the captain had operated only on A340-313K and A340-541 and was not current on the A330-243. The captain's relevant qualifications and aeronautical experience are outlined in Table 1.

**Table 1: Captain's relevant qualifications and aeronautical experience**

Type of licence	Airline Transport Pilot (Aeroplane) Licence
Total flying hours	8,195 hours
Total flying hours on the A340-541	1,372 hours
Total flying last 90 days	218.1 hours (27 flights)
Total flying last 90 days on the A340-541	104 hours (11 flights)
Total flying last 30 days	98.9 hours (11 flights)
Total flying last 30 days on the A340-541	69.3 hours (7 flights)
Total flying last 28 days	85.2 hours (10 flights)
Total flying last 28 days on A340-541	55.6 hours (6 flights)
Total flying last 7 days	14.5 hours (2 flights)
Total flying last 7 days on the A340-541	14.5 hours (2 flights)
Last proficiency check	7 October 2008
Medical certificate	Class 1 – valid till 15 October 2009, nil restrictions

The captain had operated on flights to or from Melbourne on 18 occasions during the preceding 12 months, including four occasions as part of an augmenting crew.

***First officer***

The first officer was rated on the Airbus A330-243, A340-313K and A340-541. In the preceding 90 days, the first officer had operated on all three aircraft types. The first officer’s relevant qualifications and aeronautical experience are outlined in Table 2.

**Table 2: First officer’s relevant qualifications and aeronautical experience**

Type of licence	Airline transport pilot (aeroplane) licence
Total flying hours	8,316 hours
Total flying hours on the A340-541	425 hours
Total flying last 90 days	199.2 hours (31 flights)
Total flying last 90 days on the A340-541	124.2 hours (13 flights)
Total flying last 30 days	89.7 hours (10 flights)
Total flying last 30 days on the A340-541	82.9 hours (8 flights)
Total flying last 28 days	76.2 hours (9 flights)
Total flying last 28 days on the A340-541	69.3 hours (7 flights)
Total flying last 7 days	21.3 hours (4 flights)
Total flying last 7 days on the A340-541	14.5 hours (2 flights)
Last proficiency check	5 February 2009
Medical certificate	Class 1 – valid to 6 August 2009, nil restrictions

The first officer had operated on flights to or from Melbourne on 14 occasions during the preceding 12 months, including four occasions as part of an augmenting crew.

**1.4.2 Augmenting flight crew**

***Augmenting captain***

The augmenting captain was rated on the Airbus A330-243, A340-313K and A340-541. In the preceding 90 days, he had operated on all three aircraft types. The augmenting captain’s relevant qualifications and aeronautical experience are outlined in Table 3.

**Table 3: Augmenting captain's relevant qualifications and aeronautical experience**

Type of licence	Airline transport pilot (aeroplane) licence
Total flying hours	12,486.8 hours
Total flying hours on A340-541	694.1 hours
Total flying last 90 days	175.3 hours (46 flights)
Total flying last 90 days on A340-541	44.3 hours (6 flights)
Total flying last 30 days	80.9 hours (16 flights)
Total flying last 30 days on A340-541	44.3 hours (6 flights)
Total flying last 28 days	70.5 hours (13 flights)
Total flying last 28 days on A340-541	44.3 hours (4 flights)
Total flying last 7 days	22.3 hours (4 flights)
Total flying last 7 days on A340-541	22.3 hours (4 flights)
Last proficiency check	28 December 2008
Medical certificate	Class 1 – valid to 7 May 2009, nil restrictions

The augmenting captain had operated on flights to or from Melbourne on seven occasions during the preceding 12 months, including three occasions as part of an augmenting crew.

***Augmenting first officer***

The augmenting first officer was rated on the Airbus A330-243, A340-313K and A340-541. In the preceding 90 days, he had operated on all three aircraft types. The augmenting first officer's relevant qualifications and aeronautical experience are outlined in Table 4.

**Table 4: Augmenting first officer's relevant qualifications and aeronautical experience**

Type of licence	Airline transport pilot (aeroplane) licence
Total flying hours	6,438 hours
Total flying hours on A340-541	543 hours
Total flying last 90 days	153.6 hours (34 flights)
Total flying last 90 days on A340-541	33.4 hours (5 flights)
Total flying last 30 days	60.4 hours (11 flights)
Total flying last 30 days on A340-541	22.3 hours (4 flights)
Total flying last 28 days	54.4 hours (10 flights)
Total flying last 28 days on A340-541	22.3 hours (4 flights)
Total flying last 7 days	22.3 hours (4 flights)
Total flying last 7 days on A340-541	22.3 hours (4 flights)
Last proficiency check	5 March 2009
Medical certificate	Class 1 – valid to 6 July 2009, nil restrictions

The augmenting first officer had operated on flights to or from Melbourne on seven occasions during the preceding 12 months, including three occasions as part of an augmenting crew.

### **1.4.3 Augmenting flight crew procedures**

On long-range sectors, where the flight time extended beyond the permissible flight duty time for the operating flight crew, a second or 'augmenting' crew was carried to allow the operating flight crew to rest during the cruise segment of the flight. The augmenting crew were positioned in the cockpit observer seats for takeoff.

The augmenting crew members' responsibilities were listed in the operator's *Flight Operations Manual* as follows:

#### Augmented Crew Responsibilities

Their responsibilities include (but are not limited to):

- Participate in Pre (&Post) flight Briefings and Flight Planning.

Whilst onboard the aircraft, and not resting:

- Participate in flight deck briefings and to actively monitor the flight path of the aircraft and actions of the PF [pilot flying] and PNF [pilot not flying].
- Maintain a situational and operational awareness.
- Bring to the attention of the operating crew any abnormalities or departure from SOPs and previously briefed intentions.
- Duties delegated by the PIC [pilot in command].
- Note: Use of the augmenting pilot to assist with flight preparation and other duties does not absolve any operating pilot of his SOP defined responsibilities. Care must be taken to ensure that no aspects of any operational responsibilities are overlooked.

Those requirements conformed with UAE Civil Aviation Regulation (CAR) CAR-OPS 1.940, 'Composition of Flight Crew'.

All four flight crew members reported that the presence of an augmenting crew in the cockpit during the pre-departure phase created a distraction for the operating flight crew.

### **1.4.4 Crew resource management**

The communication between the operating crew members during the taxi and takeoff was in accordance with procedures and reflective of an open and effective cockpit environment. The first officer was the pilot flying during the takeoff and for the majority of the flight, so the captain conducted most of the communications with ATC and the cabin. The captain also asked the augmenting crew to calculate the landing data for the return to Melbourne and therefore the amount of fuel to be jettisoned.

Recorded information showed that the captain also included the augmenting crew in the discussions about the landing configuration and after-landing checks that would be required on their return to Melbourne. During that time, the captain made

numerous decisions about the return to Melbourne, some of which were challenged by the crew before being resolved, in accordance with accepted crew resource management practices.

#### **1.4.5 Flight crew trip history**

The operator scheduled daily return flights from Dubai to Auckland, New Zealand via Melbourne under two flight numbers: EK406 from Dubai to Auckland, via Melbourne; and EK407 returning from Auckland to Dubai, via Melbourne. Each flight number consisted of two sectors; the accident flight was to be the second sector for EK407.

The captain and first officer departed Dubai at 1013 local time (0613 UTC) on 18 March 2009 as the operating crew of Flight EK406. The duration of the sector was 13 hours and the crew arrived in Melbourne at 0613 on 19 March (1913 UTC on 18 March) (Figure 15). They were rostered off duty in Melbourne until recommencing duty for the return flight to Dubai on 20 March.

The augmenting flight crew (captain and first officer) departed Dubai 2 days earlier at 1010 local time (0610 UTC) on 16 March 2009 as the augmenting crew on Flight EK406. The flight duration was 13 hours and 13 minutes and the augmenting crew arrived in Melbourne at 0623 on 17 March (1923 UTC on 16 March). They then became the operating crew of the next sector of flight EK406 to Auckland, departing Melbourne at 0810 on 18 March (2110 UTC on 17 March) and arriving in Auckland at 1339 local time (0039 UTC on 18 March), a duration of 3 hours and 29 minutes.

The augmenting flight crew operated the return sector from Auckland to Melbourne on 19 March as the operating crew of Flight EK407. The flight departed Auckland at 1845 local time (0545 UTC) and arrived in Melbourne at 2050 (0950 UTC), a duration of 4 hours and 5 minutes (Figure 15). The sectors from Melbourne to Auckland and return were operated as 2-crew operations.

The flight crews were rostered off duty between their respective sectors as shown in Figure 15.

#### **1.4.6 Flight crew alertness and fatigue**

Fatigue can be defined as a state of impairment that can include physical and/or mental elements associated with lower alertness and reduced performance. Fatigue can impair individual capability to a level where a person cannot continue to perform tasks safely and/or efficiently.

The investigation examined the likelihood that the operating flight crew were fatigued at the time of the accident and the effect that fatigue may have had on their performance. Using sleep/wake data provided to the investigation by the operating flight crew, the fatigue biomathematical modelling system *Fatigue Avoidance Scheduling Tool* (FAST)<sup>13</sup> was used to assess the flight crew's task effectiveness. FAST allows the user to input the quality of sleep as well as the duration of any sleep and work.

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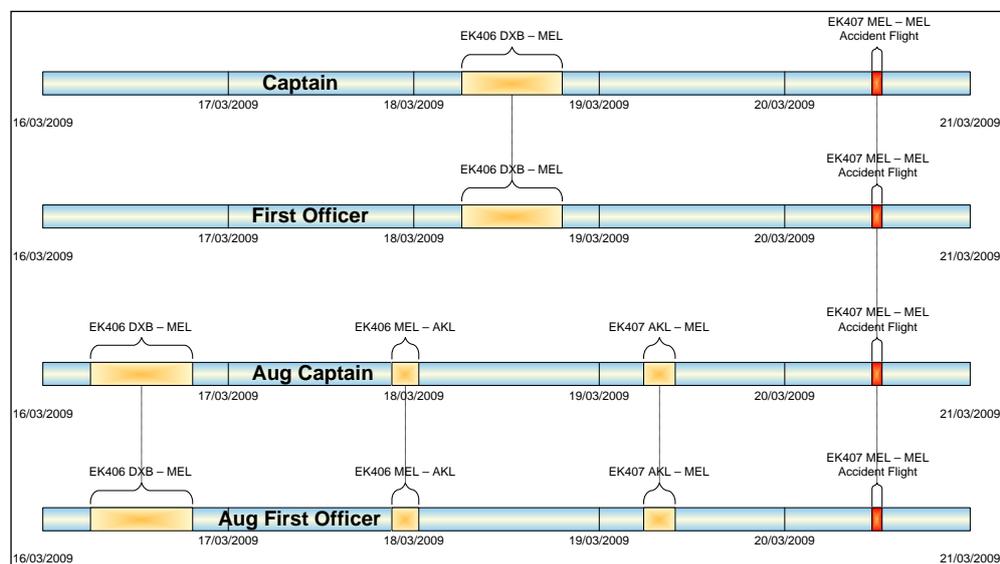
<sup>13</sup> Eddy, D.R.; Hursh, S.R. (2001). *Fatigue Avoidance Scheduling Tool (FAST)*. Brooks AFB, TX: AFRL/HEOA; 2001; Report No: AFRL-HEBR-TR-2001-0140.

The calculations used by FAST were designed to produce a score denoting an individual's task effectiveness. Both operating flight crew members had FAST scores that were towards the top of the effectiveness range. The operator also assessed flight crew fatigue using a different biomathematical modelling tool. The operator's results for the operating flight crew from that tool correlated closely with the FAST scores.

The operating captain reported having 6 hours sleep in the 24 hours prior to the occurrence and 16 hours sleep in the 48 hours prior to the occurrence. The operating first officer reported having 8 hours sleep in the previous 24 hours and 12 hours sleep in the previous 48 hours.

There were no salient indications recorded on the CVR to indicate that either flight crew were fatigued; such as yawning and prolonged silence, or the disengagement of crew from conversations.

**Figure 15: Flight crew flight history**



Note: Times and dates are relative to UTC.

DXB = Dubai, United Arab Emirates

UTC + 4 hours

MEL = Melbourne, Australia

UTC + 11 hours

AKL = Auckland, New Zealand

UTC + 13 hours

### 1.4.7 Cabin crew

There were 14 cabin crew members on board the flight, including the purser and two senior flight stewards. The purser was responsible for the passenger cabin and managed the first class section. The two senior flight stewards managed the business and economy cabins during cruise, and reported directly to the purser.

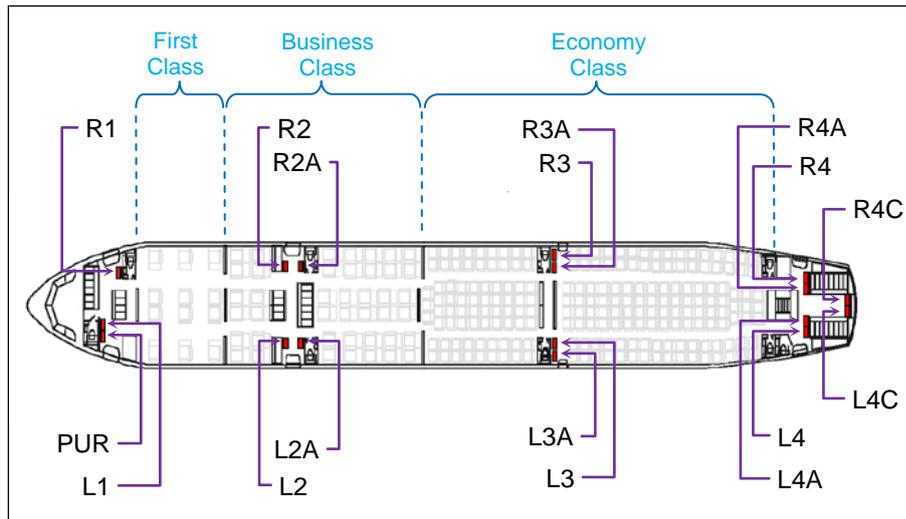
The purser had over 6 years experience with the operator, with 4 months experience as purser. The two senior flight stewards had 5 and 6 years total experience with the operator.

The experience of the remaining 11 cabin crew ranged from 3 weeks to 6 years with the operator. All cabin crew were current in respect of the operator's emergency procedures proficiency requirements.

## Seating arrangement

The purser was positioned at door left 1 (L1), one senior flight steward was positioned at door L4 and the other was positioned at L4C (Figure 16). The remaining cabin crew were positioned throughout the cabin. According to cabin crew reports and the operator's procedures, the senior flight steward who was located at L4C should have been at R2A, which remained vacant for the entire flight.

**Figure 16: Cabin crew seating arrangement**



Source: Cabin Crew Emergency Manual

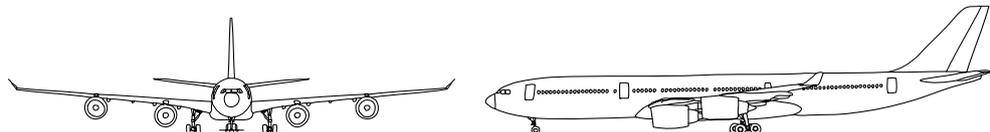
PUR – purser

## 1.5 Aircraft information

### 1.5.1 General

The aircraft was a low-wing, high-capacity transport category aircraft that was manufactured in France in 2004 (Figure 17). The aircraft was equipped with four Rolls-Royce Trent 553-6 high-bypass turbofan engines and was configured to seat 258 passengers in a three-class cabin. The aircraft was designed and certificated to be operated by two pilots.

**Figure 17: A340-541**



Source: A340-500 FCOM Vol 1

The aircraft was purchased new by the operator and issued with a UAE General Civil Aviation Authority (GCAA) Certificate of Registration on 30 November 2004.

Additional information on the aircraft and its systems is at Appendix B.

## 1.5.2 Tailstrike protection and detection

The aircraft did not have a tailskid to protect the fuselage from damage in the event of a tailstrike. Protection against a tailstrike was provided by standard operating procedures, reference information and the aircraft's flight control system.

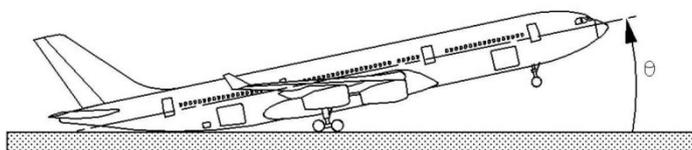
### ***On-ground pitch attitude limits***

In June 2004, the aircraft manufacturer issued a Flight Crew Operating Manual (FCOM) Bulletin titled *Avoiding Tailstrikes*. That bulletin listed the on-ground pitch attitude limits ( $\theta$  in Figure 18) for the A340-500 series aircraft as follows:

13.5° - with the main landing gear oleos.<sup>14</sup> fully extended

9.5° - with the main landing gear oleos fully compressed.

**Figure 18: On-ground pitch attitude limits**



Source: Airbus FCOM Bulletin No 807/1

### ***Tailstrike pitch limit indicator***

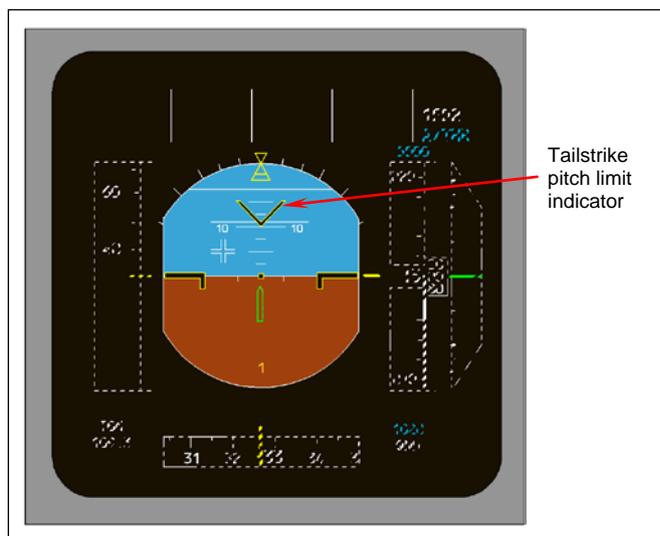
A pitch limit indicator was displayed on the primary flight display during takeoff and landing. The pitch limit indicator was in the form of a 'V' symbol (Figure 19), the lower point of which represented the maximum pitch attitude attainable on the ground without striking the tail.

During takeoff, the indicator progressed from the pitch limit value with the main landing gear oleos compressed, to the pitch limit value with the main landing gear oleos fully extended. The indication automatically disappeared from the primary flight display 3 seconds after lift-off, when the risk of a tailstrike was considered to be no longer present.

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<sup>14</sup> A telescopic shock absorber in an aircraft's landing gear that is used to absorb the vertical energy during landing.

**Figure 19: Tailstrike pitch limit indicator on the primary flight display**



Source: A340-500 FCOM Vol 1

Note: example shown for illustration only and does not contain data from the accident flight

### ***Flight control system protection***

The aircraft's flight control system incorporated a degree of tailstrike protection; however, it was not a 'hard' protection.<sup>15</sup> On the ground, pitch control was in ground mode, which resulted in a direct relationship between the sidestick and elevator deflection (known as direct law).<sup>16</sup> This differed from normal law flight mode, when the sidestick demanded a flight load factor<sup>17</sup>, with full flight envelope protection.<sup>18</sup> The A340-500 FCOM, Vol. 1 stated:

The rotation maneuver is flown in direct law, with some damping provided by pitch rate and by estimated tail clearance margin feedbacks, to avoid tailstrike.

To prevent a tailstrike in ground mode, the aircraft's flight control computers monitored the pitch rate and estimated the tail clearance margin. If the system determined that a tailstrike was possible, the flight control computers reduced the amount of elevator deflection for the given sidestick position to reduce the pitch rate (termed 'damping' by the manufacturer).

The pilot could override the protection by a sidestick command that was greater than the reduction in elevator deflection provided by the damping.

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<sup>15</sup> That is, it was designed to reduce the likelihood of a tailstrike, not positively stop it from occurring.

<sup>16</sup> A direct relationship between the sidestick and the elevator deflection means that the elevator deflection is directly proportional to the position of the sidestick. For example, moving the sidestick to the fully backward position results in a full elevator up deflection and similarly, moving the sidestick forward half of the full travel will deflect the elevator downwards half of its full deflection.

<sup>17</sup> The vertical acceleration relative to gravity, often referred to in terms of 'g'. For example, a load factor of 3, or 3 g, is three times the acceleration due to gravity.

<sup>18</sup> The flight control system included protections against excessive load factor, pitch attitude, angle of attack, and speed to prevent the flight crew exceeding the aircraft's flight envelope limitations.

### ***Rotation technique***

The A340-500 Flight Crew Training Manual (FCTM) provided guidance on the rotation technique, including rotation rate as follows:

The initial rotation rate takes time to establish. For a given sidestick input, once it has developed, it remains relatively constant. It is typically between 2 and 3° /sec.

and that, for the A340-541:

At take off, the typical all engine operating attitude after lift-off is about 15°.

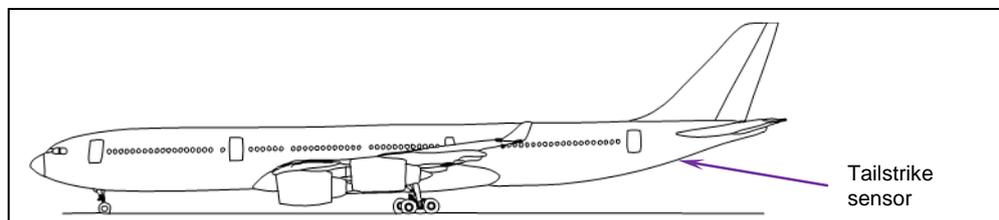
### ***Lift-off pitch attitude***

The manufacturer advised that the expected lift-off pitch attitude for a correctly-configured aircraft using the normal rotation technique would be around 8°.

### ***Electronic centralised aircraft monitor tailstrike indication***

The aircraft was equipped with a tailstrike detector that was mounted on the underside of the rear fuselage (Figure 20). When the sensor detected a tailstrike, a single chime caution tone and an amber TAIL STRIKE message was generated on the upper electronic centralised aircraft monitor (ECAM) engine/warning display (Figure 21). The caution was inhibited until the aircraft had left the ground to minimise flight crew distraction during the critical take-off phase.

**Figure 20: Tailstrike sensor location**



Source: A340-500 FCOM Vol 1

## **1.6 Meteorological information**

Melbourne Airport automatic terminal information service (ATIS).<sup>19</sup> 'Uniform' had effect from 2150 (1050 UTC). That broadcast included a wind of 250° magnetic (M) at 5 kts with a maximum downwind on runway 16 of 2 kts, an outside air temperature of 17 °C, CAVOK,<sup>20</sup> and a QNH.<sup>21</sup> of 1015 hPa. ATIS 'Uniform' was superseded by ATIS 'Victor' at 2238.

<sup>19</sup> The Automatic Terminal Information Service (ATIS) included current weather information for the airport. The revision status of the information was indicated by successive letters of the phonetic alphabet.

<sup>20</sup> Ceiling and visibility OK, meaning that visibility, cloud and present weather better than prescribed conditions. For an aerodrome weather report, those conditions are visibility 10 km or more, no cloud below 5,000 ft or cumulonimbus cloud and no other significant weather within 9 km the aerodrome.

The moon set at 1500 and the sun at 1933 that day, and the end of daylight was at 1959.<sup>22</sup> This meant the takeoff was conducted in darkness with no moonlight. The captain reported that the takeoff was ‘very dark’ due to the lack of lighting in the area surrounding runway 16.

**Figure 21: ECAM tailstrike caution message**



Source: A340-500 FCOM Vol 1

Note: Example shown for illustration only and does not contain data from the accident flight.

## 1.7 Aids to navigation

The flight crew members were using visual references for the takeoff in accordance with standard operating procedures, independent of any ground-based navigation aids.

<sup>21</sup> The QNH is a figure that represents the theoretical mean sea level air pressure at a point. The QNH figure is used to set an altimeter so that it indicates the altitude (height above mean sea level) at that point.

<sup>22</sup> Geoscience Australia website <http://www.ga.gov.au>, accessed 28 July and 19 August 2010.

## 1.8 Communications

Communication with ATC was primarily through very high frequency (VHF) radio with both Melbourne departures and tower using separate VHF frequencies. Some information that was provided by ATC, including ATIS, was obtained via the aircraft communications addressing and reporting system (ACARS).<sup>23</sup> All radio communication with ATC was recorded on the CVR.

All communications with the operator in Dubai were via ACARS. There were no reported problems with the operation or function of the ACARS system.

All recorded communications between the cockpit and cabin crew were clear and there was no indication of any misunderstanding between the flight and cabin crew at any time. Communications among the cabin crew were not recorded, nor were they required to be.

### 1.8.1 Communication within the passenger cabin

The captain requested that the cabin crew remain seated for the duration of the flight and that all communication between the cabin crew was via the interphone system. The only report of any difficulty with the interphone system was from the cabin crew member who was seated at door R2 who reported that she was unable to reach the interphone from her door operator position at R2 (see Figure 22).

Seat position R2A was within reach of the interphone, but that seat was vacant for the duration of the flight, as the senior flight steward who should have normally been seated there was actually seated at L4C. The crew member who was seated at R2 reported having to rely on the cabin crew member seated at door L2 to convey pertinent information from the purser, and from the senior flight steward who was seated at L4. It was reported that the senior flight steward had been erroneously advised to occupy the L4C seat.

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<sup>23</sup> A wireless communication system that was used to transmit and receive data to and from the aircraft. The aircraft also had a printer, located between the flight crew in the centre console, which enabled ACARS messages to be printed out for later reference.

**Figure 22: Door R2 interphone**



## 1.9 Aerodrome information

### 1.9.1 Runways

Melbourne airport had two runways that were oriented north-north-west and south-south-west (runway 16/34) and east and west (runway 09/27) (Figure 23).

Runway 16/34, aligned 160/340° M, was 3,657 m long and 60 m wide, and was constructed of asphalt with concrete ends. A clearway was located at the southern end of runway 16 that extended 120 m from the end of the runway and included a stopway of 60 m. The elevation at the arrival end of runway 16 was 432 ft and the runway sloped down to 330 ft at the departure end. The ground surrounding the end of runway 16 consisted of dry soil, with a sparse cover of dry grass.

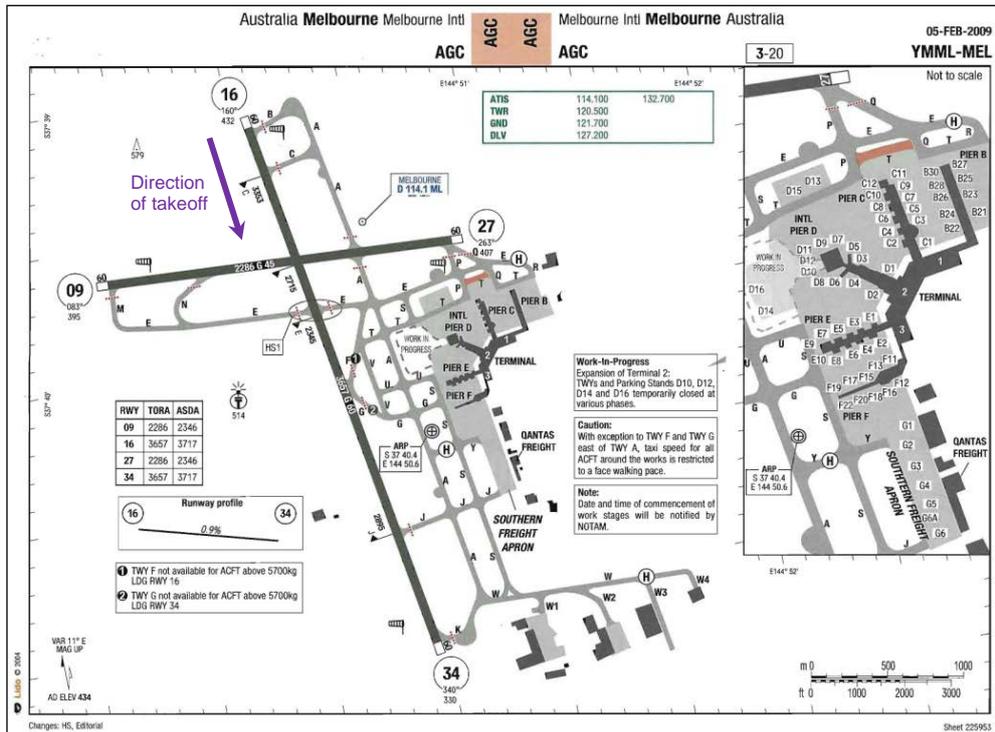
### 1.9.2 Lighting

The taxiway and runway edge and centreline lighting was in accordance with the applicable ICAO standard.<sup>24</sup> The runway centreline lights were white until 900 m from the end of the runway. From 900 m to 300 m from the end of the runway, they were alternating red and white and the final 300 m of the runway centreline lighting was all red.

Other than the apron areas immediately around the terminal facilities, the airport was not provided with general area lighting, nor was it required to be.

<sup>24</sup> ICAO Annex 14, *Aerodromes*, Volume 1, *Aerodrome and Operations*, 5<sup>th</sup> edition, July 2009.

Figure 23: Airport information chart



Note: This chart is a copy of the actual chart used by the flight crew on the night of the accident

Direction of takeoff added by investigation.

### 1.9.3 Obstacles beyond runway 16

There were a number of obstacles beyond the end of runway 16 in the direction of takeoff, including an ILS localiser antenna array and a sequenced lead-in strobe lighting system.

An ILS consists of glideslope<sup>25</sup> and localiser<sup>26</sup> transmitters. The runway 16 localiser antenna system included a transmitter antenna array and a near-field monitor antenna. The near-field monitor antenna was 200 m from the end of the runway, with the top of the antenna about 0.4 m below the height of the departure end of the runway. The localiser antenna array was 328 m from the end of the runway, with the top of the array about 0.1 m below the height of the departure end of the runway.

Runway 34 had a sequenced lead-in strobe light system that consisted of three strobe lights mounted on concrete pads. The strobe light struck by the aircraft was 177 m from the end of the runway, with the top of the light about 1.5 m below the height of the departure end of runway 16.

<sup>25</sup> Part of an ILS that provides vertical flightpath tracking guidance.

<sup>26</sup> Part of an ILS that provides lateral flightpath tracking guidance.

The localiser antennas and the strobe lights were reported by the airport operator to have been designed and constructed as 'frangible' structures in accordance with the applicable ICAO manual.<sup>27</sup>

## 1.10 Flight recorders

The aircraft was equipped with three flight recorders as follows:

- a cockpit voice recorder (CVR)
- a flight data recorder (FDR)
- a digital ACMS.<sup>28</sup> recorder (DAR).

The fitment of an FDR and CVR was mandatory for this aircraft and the audio recorded on the CVR and parameters recorded on the FDR were defined by regulation. The recorded flight and audio data was stored within the crash-protected memory modules of these two recorders.

As noted earlier, the FDR was dislodged from its mounting rack and ceased recording at about the time of the initial tailstrike at 2232:05.

The DAR was an optional recorder that was used for flight data and aircraft system monitoring as stipulated by the operator's requirements. The DAR parameters included most of the FDR parameters, with additional parameters as configured by the operator. The information recorded on the DAR was stored on a removable memory card that was not crash-protected. A graphical representation of the pertinent information from the DAR for the takeoff is at Appendix C.

An animation of the takeoff, based on DAR information, has been published as part of this report and is available at [www.atsb.gov.au](http://www.atsb.gov.au)

## 1.11 Fire

Examination of the rear fuselage found no indications of a fire that could account for the smoke reported in the rear cabin.

The apparent smoke that was reported by the cabin crew was consistent with dust entering the fuselage through the abrasion when the tail was in contact with the ground beyond the end of the runway. The change in the pitch attitude while the aircraft was being configured for the approach altered the airflow around the rear fuselage, may have resulted in some of the dust collected in the abraded area entering the rear passenger cabin. The heat generated when the fuselage skins were abraded on the runway may have produced some vapours from the synthetic materials in that area (for example, paints and insulation materials) that produced an odour similar to combustion products.

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<sup>27</sup> ICAO Doc 9157-AN/901, *Aerodrome Design Manual*, Part 6 'Frangibility' 1<sup>st</sup> edition, 2006.

<sup>28</sup> Aircraft condition monitoring system.

## 1.12 Tests and Research

The inadvertent use of erroneous take-off data for performance calculations and subsequent takeoffs has been the subject of two research studies, one by the Laboratoire d'Anthropologie Appliquée (LAA).<sup>29</sup> and the other by the Australian Transport Safety Bureau (ATSB). Both studies highlighted the widespread, systemic nature of this issue, with the ATSB paper identifying 31 occurrences from a 20-year period. In addition, the studies offered considerable insight into the factors influencing the use of erroneous data for takeoff and were used to conduct a more targeted comparison between the accident flight and similar events.

### 1.12.1 Laboratoire d'Anthropologie Appliquée study

The French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA).<sup>30</sup> and the Direction générale de l'Aviation civile (DGAC).<sup>31</sup> commissioned the LAA, to study the processes relating to the use of erroneous take-off performance parameters following two tailstrike accidents in France. The objective was to examine why skilled and highly trained crews were unable to detect the errors. To do this, the study examined literature on take-off decision making, aircraft manufacturer's guidance on take-off reference speeds, response times during takeoff, skill decay, and interaction with automation, specifically the flight management system (FMS) and Multi-purpose Control Display Unit (MCDU). The study then conducted an ergonomic assessment of the interface units used in the two tailstrike accidents, as well as examining the operator's procedures from each airline and conducting a survey of pilots. In May 2008, the BEA issued the LAA report, *Use of Erroneous Parameters at Takeoff*,<sup>32</sup> which presented the findings from that study.

The conclusions presented in the report included:

- The variety of events show that the problem of determining and using takeoff parameters is independent of the operating airline, of the aircraft type, of the equipment and of the method used,
- Half the crews who responded to the survey carried out in one of the airlines taking part had experienced errors in parameters or configuration at takeoff, some of which involved the weight input into the FMS,
- Checks on the "takeoff parameter calculation" function can be shown to be ineffective because they consist of verifying the input of the value but not the accuracy of the value itself,

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<sup>29</sup> The Laboratoire d'Anthropologie Appliquée (LAA) is part of L'Université Paris Descartes, France.

<sup>30</sup> The Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA) is the French agency with responsibility for technical investigations into civil aviation accidents or incidents under its jurisdiction.

<sup>31</sup> The Direction générale de l'Aviation civile (DGAC) is the French agency with responsibility for the regulation of civil aviation under its jurisdiction.

<sup>32</sup> A copy of that report is available for download from the BEA website at <http://www.bea.aero/en/index.php>.

- The FMS studied allow insertion of weight and speed values that are inconsistent or outside the operational limits of the aircraft concerned. Some accept an omission to enter speeds, without the crew being alerted,
- Time pressure and task interruptions are frequently cited in surveys as common factors contributing to errors. The observations showed that the crews' work load increases as the departure time approaches and that the normal operation actions of the captain were all the more disrupted,
- Pilots' knowledge of the order of magnitude of these parameter values, determined by empirical methods, is the most frequently cited strategy used to avoid significant errors.

Despite this reported knowledge of benchmarking using 'orders of magnitude'<sup>33</sup> as a strategy to avoid significant errors, the report also noted:

... that the failure of the takeoff parameters to remain in working memory for a long time does not allow the pilot to create in [sic] internal representation of the values. This explains why pilots don't (or no longer) possess orders of magnitude of speeds, so making it difficult even in the event of "gross" error to raise a doubt over values incompatible with the flight.

The report suggested that to improve their capability to recognise errors of orders of magnitude, flight crew need to have the take-off performance parameters stored in their long term memory.

### 1.12.2 Australian Transport Safety Bureau research study

Given the number of occurrences involving the use of erroneous take-off data both in Australia and internationally, the ATSB initiated a research study. The objectives of that study were:

- ...to present a worldwide perspective of accidents and incidents (collectively termed occurrences) involving take-off performance parameter errors.
- to provide an overview of these events occurring within Australia and internationally, between the period 1 January 1989 and 30 June 2009, and
- to explore the nature of these errors and identify the factors that contributed to these events.

In January 2011, the ATSB released the findings in Aviation Research and Analysis Report AR-2009-052, *Take-off performance parameter errors: A global perspective*.<sup>34</sup>

The report identified 20 international and 11 Australian occurrences within the 20-year period. These occurrences were limited to those investigated by international agencies and Australian occurrences reported to the ATSB. It is probable that the calculation of erroneous take-off data is a larger problem than the research paper could determine, because in most cases the defences caught the error before an adverse outcome, such as a tailstrike.

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<sup>33</sup> In this context, the term 'orders of magnitude' refers to the flight crew's ability to assess the reasonableness off the relationship between the aircraft's gross weight and the take-off reference speeds.

<sup>34</sup> A copy of the report can be obtained from the ATSB website at [www.atsb.gov.au](http://www.atsb.gov.au).

The research report found that the types of errors had multiple origins and involved a range of devices and systems. For example, crew actions could result in the wrong figure being used in a system, in data being entered incorrectly, data not being updated and data being excluded in a range of systems including performance documentation, laptop computers, FMS and aircraft communications addressing and reporting systems.

The occurrences reviewed indicated the systemic nature of the problem, and the fact that it manifests irrespective of location, aircraft type, operator, and flight crew. In some cases, the errors were by dispatchers situated away from the cockpit, thereby removing the error origin from the cockpit entirely.

The report highlighted the varied factors contributing to the use of erroneous take-off performance parameters, including distraction and task experience, as well as some of the challenges in identifying these errors, such as ineffective procedures and the design of automated systems. It was found that robust defences are needed to help detect and prevent these errors.

### **1.12.3 Detailed review of similar occurrences to the accident**

The investigation used the research papers above to identify those events which shared multiple similarities with this accident.

Details of those events, including explanation of the event to provide the context of the error and subsequent use of erroneous data, are provided in Appendix D. Three events that shared a significant degree of similarity with this accident are summarised below.

#### ***Boeing B767: August 1999***

Location: Copenhagen, Denmark

The first officer entered the runway in use, temperature, and other flight details into the aircraft communication addressing and reporting system (ACARS). The take-off weight (TOW) was not entered because the flight crew had not yet received the loadsheet. Once the loadsheet arrived, the captain entered the zero fuel weight (ZFW)<sup>35</sup> into the FMS. The first officer then entered the ZFW into the aircraft TOW prompt in ACARS. The calculations were made at the mainframe computer and sent back via ACARS to the flight crew.

The relief pilot noticed that the mean aerodynamic chord (MAC) was 7.0%, which did not appear to be correct. According to the loadsheet, the MAC was 19.0%. The first officer amended the ACARS accordingly. The captain entered the V speeds into the FMS.

During the takeoff, the tail skid pan came into contact with the runway, the aircraft failed to become airborne and the captain rejected the takeoff.

It was determined that the first officer had limited experience on the B767 but had previously flown the McDonnell Douglas MD-80, where the ZFW was the take-off input parameter. The flight crew did check the performance data; however, their

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<sup>35</sup> The zero fuel weight is the total weight of an aircraft for a specific type of operation including the traffic load (cargo, passengers and bags), but excluding the usable fuel.

attention was drawn to the MAC and not the TOW and V speeds. The layout of the ACARS print out could have resulted in a misinterpretation of the TOW, with the crew possibly believing they had 'found the value they were looking for' but at the wrong location. In addition, the flight crew's normal procedures may have been interrupted by the relief pilot observing the MAC value discrepancy which, in turn, may have stopped them from checking the remaining take-off data.

### ***Boeing B747: March 2003***

Location: Auckland, New Zealand

During early pre-departure preparations, the flight crew determined that additional 7,700 kg fuel would be required to that already on the aircraft. When they boarded the aircraft about 15 mins prior to departing, they realised that only 4,500 kg had been uploaded. They requested the additional fuel be loaded and obtained a revised loadsheet. The final loadsheet was delivered to the flight crew about the same time the aircraft was scheduled to depart.

The captain called out the ZFW and TOW figures and the stabiliser trim setting for the first officer to write on the take-off data card. During this transcription, the first officer recorded the TOW as 247,400 kg instead of the actual TOW of 347,400 kg. The first officer normally added the ZFW to the fuel figure to verify the TOW; however, on this flight he either added them incorrectly or did not get a chance to add them together during this stage of the pre-departure phase of flight.

The first officer used the TOW of 247,400 kg to obtain the V speeds for the takeoff and then passed the take-off data card to the captain. The captain entered the ZFW from the loadsheet into the flight management computer (FMC). The FMC automatically added the ZFW to the onboard fuel weight to display a gross weight. The captain verified that the FMC-calculated gross weight corresponded to the TOW from the loadsheet (which it did). He then entered the V speeds from the take-off data card, replacing those automatically calculated by the FMC.

Normally the third relief pilot would check the take-off data card; however, he was distracted by explaining the delay to the station manager and did not complete this check. During the takeoff, the aircraft sustained a tailstrike.

The investigation determined that, in addition to the errors noted above, the flight crew were pressured to hurry their preparations due to the delay with refuelling; that the captain had only recently converted to the B747 from the A340, which had a  $V_R$  speed range which matched the incorrect  $V_R$  speed calculated for the accident flight; there were no specific duties for the relief, or third, pilot; and the FMC did not challenge the discrepancies between the V speeds it had calculated and what the pilot entered, despite the difference being in the order of 20 kts.

### ***Airbus A340: August 2005***

Location: Shanghai-Pudong, China

About 30 minutes prior to the scheduled departure, the crew received the preliminary load information via the ACARS with a ZFW of 179,110 kg and a TOW of 259,514 kg. The captain was temporarily away from the cockpit so pre-departure preparations were delegated to the second officer. When entering the data into the ACARS take-off data calculation (TODC) computer, the ZFW was

entered instead of the TOW. Soon after, the final loadsheet was received and the TODC was not updated.

When the captain arrived, the majority of the pre-flight preparations had been completed. The captain checked the loadsheet and flight plan and the second officer read out the TODC speeds to the captain, who entered them into the MCDU. The captain observed the difference between the  $V_1$  and  $V_R$  speeds were small, but no further action was taken. The captain believed the last line of defence was incorporated into the ACARS TODC, similar to that previously experienced when he had flown the Boeing 767.

The captain and first officer verified the take-off data calculations prior to departing the gate and while taxiing, but the error was not detected. During the takeoff, the aircraft did not lift off as expected, the fuselage contacted the runway and take-off/go-around (TO/GA) thrust was applied by the first officer at the same time the aircraft became airborne.

The investigation determined that the second officer did not have immediate access to the flight plan to confirm the aircraft's TOW and the captain had been temporarily pre-occupied. The ACARS TODC computer required input of the TOW, while the MCDU required input of the ZFW. All crewmembers were previously qualified on the Boeing 767 aircraft where the TOW was similar to the ZFW of an A340. The data was entered into the TODC computer using a third MCDU which was not visible to the other two crewmembers. The captain and first officer were also qualified on the Airbus A330, where the V speeds and thrust settings are lower than that of the A340. The V speeds were verbally provided to the pilot flying; the printed calculations were not shown. The ACARS TODC software accepted unrealistic low weights and mismatched V speeds without challenge. The duties of the second officer were not clearly defined by the airline.

#### **1.12.4 Summary**

The inadvertent use of erroneous take-off performance data in transport category aircraft had resulted in a significant number of accidents and incidents prior to this accident and, as identified in the ATSB research study, the problem continues to occur. This has been identified by several investigation agencies as a significant safety issue and there have been studies into the factors involved.

The review of the previous research and similar occurrences identified that they were not specific to any particular aircraft type, operator or location, and that the only common factor in all of the events was that the crews attempted to take off with no awareness that the take-off data was not appropriate for the aircraft on that flight. Although these events differed in how the errors occurred, the outcome and effect on flight safety was similar and as such, this investigation should be viewed in the context of a much larger safety issue.

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## 2 FACTUAL INFORMATION: OPERATOR'S RISK CONTROLS

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The operator had standard operating procedures (SOPs) and training in place for flight crew covering the pre-departure preparation and the use of the electronic flight bag. The operator's documentation, training, and SOPs are summarised in this section to provide a background on the systems that were in place for the pre-departure phase of flight and what was required of the flight crew. Particular emphasis is placed on the take-off performance calculation.

### 2.1 Operational documents provided to the flight crew

The operator issued flight crew with copies of the relevant operational documentation for planning purposes. That documentation was provided in electronic form on a single compact disc (CD), which contained information on all of the operator's aircraft types (Airbus A310-300, A330-200, A340-300 and A340-500 and Boeing 777-200/300) and included the following manuals:

- *Flight Operations Manual (FOM)*. The FOM contained general company policies and procedures applicable to the entire fleet, in compliance with the current United Arab Emirates (UAE) General Civil Aviation Authority (GCAA) Operations Specifications.
- *Flight Crew Operating Manuals (FCOM)* for the Airbus A330 and A340 aircraft. The FCOMs were operational documents within Part B of the Operations Manual. The FCOMs were divided into four volumes and contained information about the aircraft systems, performance information, loading data, standard operating procedures, supplementary operational information and an FMGS guide. The aircraft-specific *Quick Reference Handbook (QRH)*, which contained some specific procedures not displayed on the ECAM, was considered part of each aircraft type's FCOM.
- *Operations Manual, Part C*, which contained specific instructions and information pertaining to navigation, communications, and aerodromes within the operator's area of operations.
- *Operations Manual, Part D*, which contained information about the operator's training and checking organisation.
- *A330/A340 Flight Crew Training Manual (FCTM)*, which was published as a supplement to the FCOMs. The FCTM was intended to provide pilots with practical information on how to operate the aircraft. The FCTM was intended to be read in conjunction with the applicable FCOM and, if there was any conflicting information, the FCOM was the overriding reference.

A current copy of the above documentation was also contained in the aircraft's electronic flight bag for reference by the flight crew during operations.

## **2.2 Pre-departure SOPs**

### **2.2.1 Take-off performance calculation**

Standard operating procedures covering the calculation of take-off performance, including the use of the EFB, were contained in the *Cockpit Preparation* and *Before Pushback or Start* sections of the operator's A340-500 FCOM Volume 3.

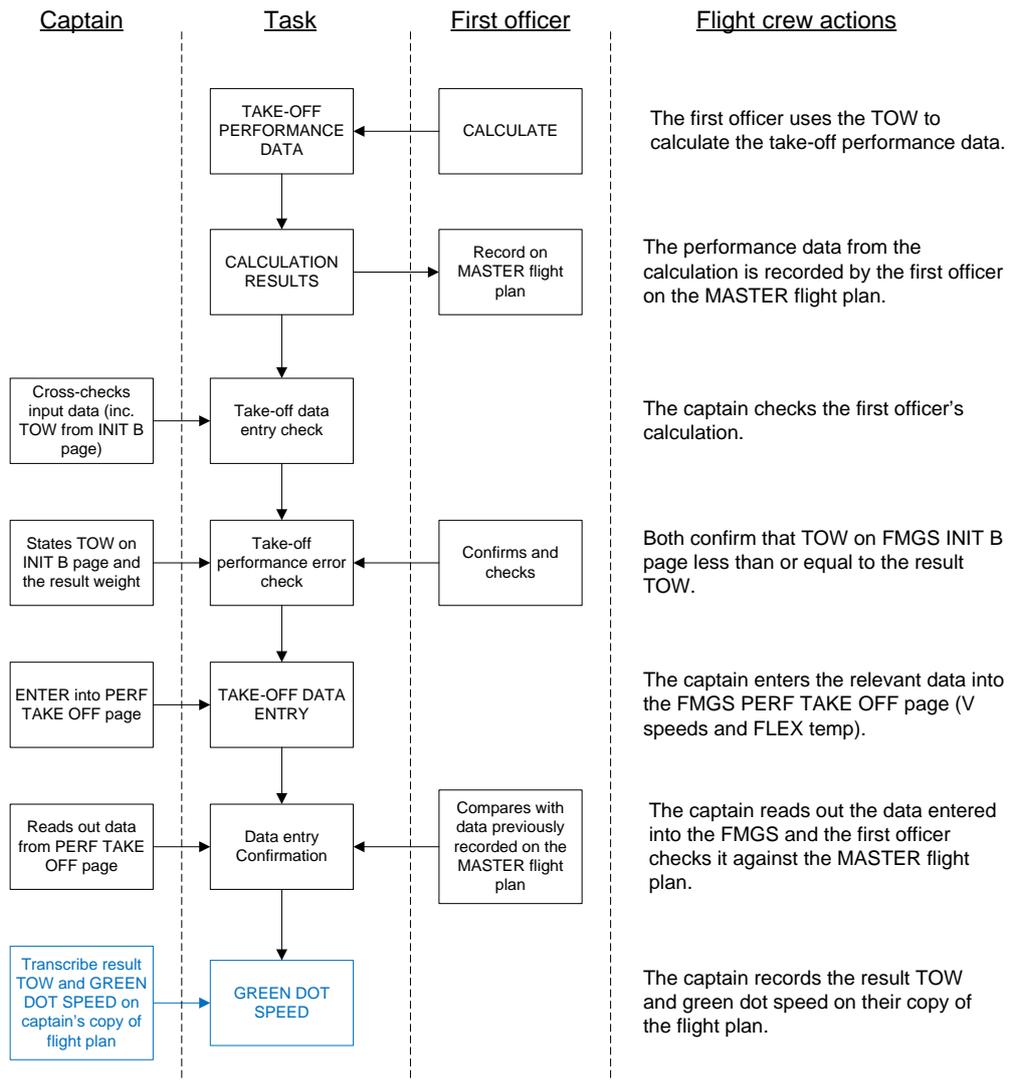
The FCTM Section 5, *Supplementary Normal Operations*, provided additional information about take-off performance calculation and task sharing, including flight crew duties and a flowchart of the take-off performance calculation and data entry process.

### **2.2.2 Overview of the operator's take-off performance calculation procedures**

The procedures for calculating the take-off performance parameters that were specified in the *Cockpit Preparation* subsection of the FCOM were presented in textual format, as shown in the copies of relevant sections provided in Appendix A. The investigation examined the procedures and compiled them into a process flowchart format to assist in the understanding of the information flow. The relevant tasks are presented in Figures 24 to 26, with some explanation of the important aspects.

Although SOPs are normally presented in operational documents in a sequential manner, in the operating environment, many of them can often be carried out in parallel or in a different order, depending on the flow of information into the cockpit. According to FCOM procedure 3.03.06, on receipt of the revised ZFW, the flight crew was required to, amongst other items, calculate and check the take-off performance data before entering the results into the FMGS and crosschecking those entries. The process flowchart presented in Figure 24, is a combination of the above procedure and the FCOM 3.03.91 briefing guide.

**Figure 24: Take-off performance calculation and error check**

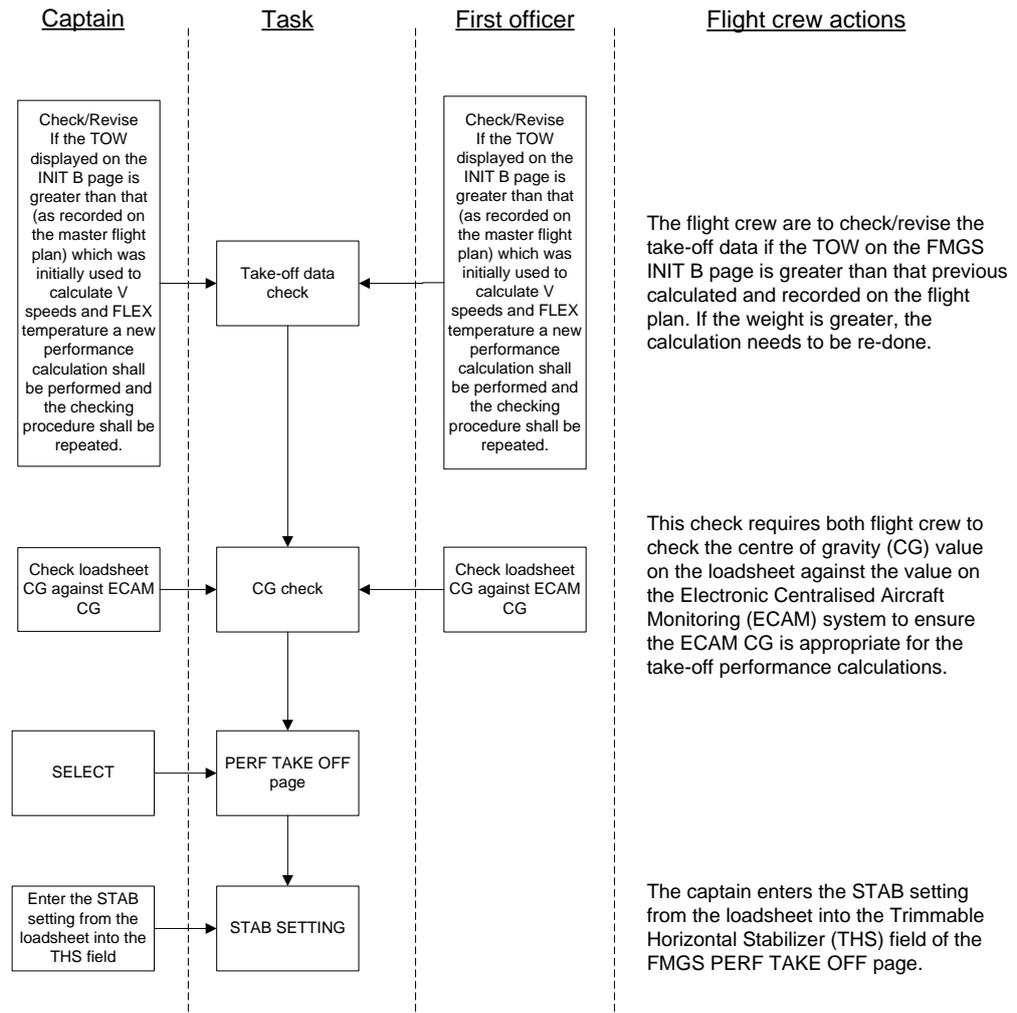


Notes:

- Items presented in blue are those that appear only in the FCOM 3.03.91 briefing guide.
- The INIT B page (second page of the FMGS initialisation pages) included the aircraft's zero fuel weight, fuel weights and take-off weight. Further information can be found in Appendix B.8.
- The PERF TO page was the page in the performance section of the FMGS that contained the performance information pertaining to the take-off phase of the flight. Refer to Appendix B.9 for more information on the PERF TO page.

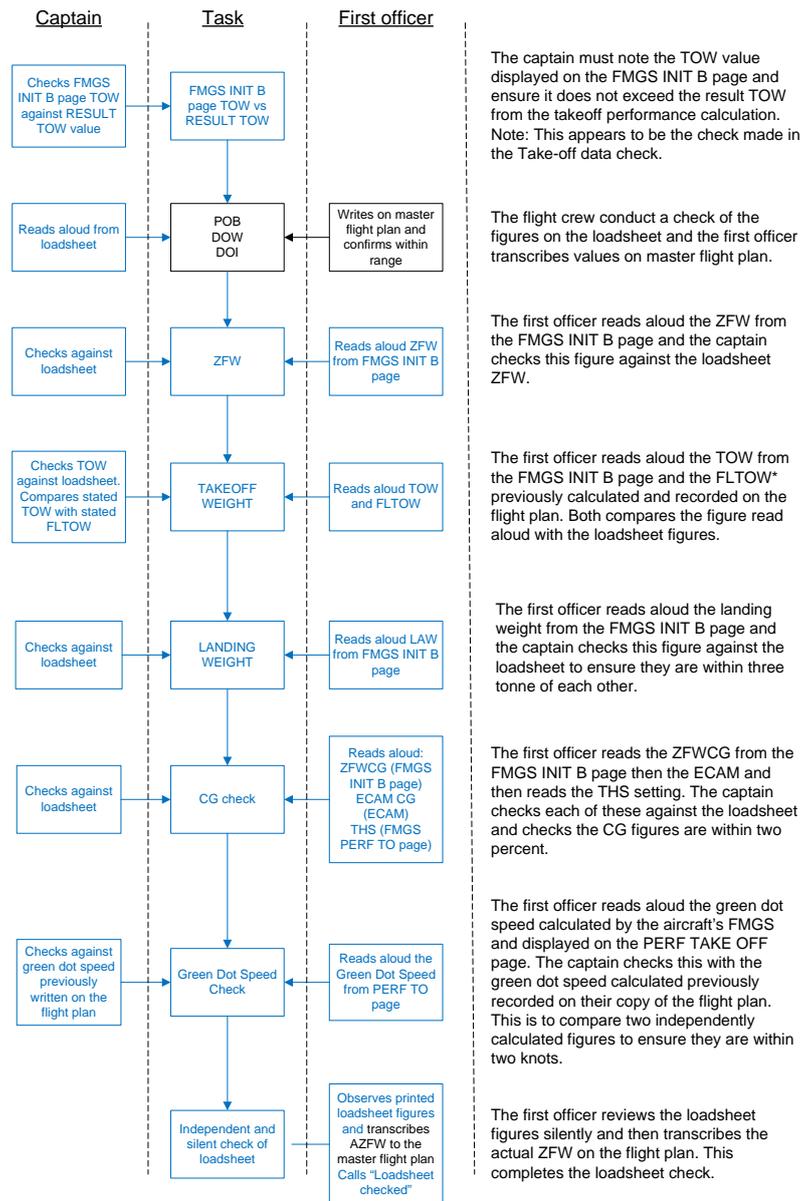
When the loadsheet<sup>37</sup> is available, and the other applicable procedures completed, the flight crew commence the *Before Pushback or Start* procedure specified in FCOM 3.03.07 (Appendix D). In that procedure, the captain checks the loadsheet and updates any applicable fields in the FMGS, before both crew are required to again compare the TOW in the FMGS with the TOW being used to derive the take-off parameters (the result TOW), prior to completing the FMGS data entry (Figure 25), and performing the loadsheet confirmation procedure (Figure 26).

**Figure 25: Take-off data**



<sup>37</sup> A document that was prepared by the operator and detailed the aircraft's weight and centre of gravity information based on the fuel, passenger, and cargo loads for the particular flight. The loadsheet contained information such as the zero fuel weight, take-off weight, and landing weight. A copy of the loadsheet that was received and printed by the flight crew is at Appendix H.2.

**Figure 26: Loadsheet confirmation procedure**



Notes:

- Items presented in blue are those that appear only in the FCOM 3.03.91 briefing guide.
- (\*) This is the only place that the flex limiting take-off weight (FLTOW) is mentioned. The weight recorded on the master flight plan under the heading FLTOW is the weight used in the take-off performance calculation (that is, the result weight).

### 2.2.3 Last minute changes

During normal operations, small changes additions or subtractions to the aircraft's weight and balance, known as 'last minute changes', may occur shortly before departure. These changes may be due to a variety of reasons such as late passenger arrivals. So that flights were not unnecessarily delayed, the operator permitted the flight crew to make minor alterations to the weight and balance information on the loadsheet without the need to issue a new loadsheet.

To maintain control over the aircraft's weight, and to ensure that the centre of gravity limits were not exceeded, the operator imposed a limit on the maximum last-minute change that could be made by the flight crew. That limit varied according to the aircraft type; the limit for the A340-541 being 1,000 kg (FOM *Handling Operations*).

The operator's procedures in the FOM required the flight crew to check that the take-off weight that was used in the take-off performance calculation was based on the take-off weight after the last-minute change was applied. There was no requirement or procedure to include an allowance in the original take-off performance calculation that anticipated a possible last-minute change. Both the captain and first officer reported that it was common practice to add an allowance for last-minute changes to the take-off weight when entering the take-off weight into the EFB, as was done in this case. They noted that this practice removed the need to redo the calculations if there was a last-minute change when workload was high. There were no last-minute changes on the accident flight.

## **2.3 Electronic flight bag**

### **2.3.1 Introduction**

At the time of the accident, the flight crew was using an electronic flight bag (EFB) that replaced the paper-based flight documentation normally carried in the aircraft, including that discussed in section 2.1. The EFB contained the Airbus Less Paper Cockpit (LPC) software, and was used to calculate take-off and landing performance data, as per the operator's preferred procedure in FCOM 3.03.06. The EFB was computer-based, allowing for automated take-off and landing performance calculations.

Airbus commenced development of the LPC concept in the mid 1990s and the system was first used in line operations in 1997. The LPC system used a Microsoft Windows XP-based Airbus software application, containing performance data derived from the computerised A340-500 FCOM. The EFB software application was hosted on a laptop computer and was often referred to as 'laptop' in the procedure. Each aircraft carried two EFBs. One was used during normal operations, the second was a backup in case of the failure of the other EFB.

### **2.3.2 EFB hardware classes and software types**

The US Federal Aviation Administration (FAA) and the European Joint Aviation Authorities (JAA)<sup>38</sup> had each issued guidance material in regard to the use of electronic flight bags. That guidance material divided EFBs into three hardware classes and three software types.

The LPC system was categorised as a Class 1 EFB because it was based on a standard commercial laptop computer that was used as stand-alone equipment in the

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<sup>38</sup> An associated agency of the European Civil Aviation Conference (ECAC), which represented the civil aviation regulatory authorities of 42 European member states. The JAA was disbanded on 30 June 2009 following a decision by the ECAC, and replaced by the European Aviation Safety Agency (EASA).

cockpit and stowed during critical phases of flight. The EFB was not permanently connected to the aircraft's power supply and did not have data connectivity to other aircraft systems, instead requiring the flight crew to manually enter data from the EFB into the aircraft's systems. The system was considered to be a portable electronic device and did not require airworthiness approval.

The LPC software within the EFB was categorised as a Type B hosted application because it was a dynamic, interactive performance application that was capable of calculating performance information based on data entered by the flight crew.

### **2.3.3 Operational approval of the EFB system**

The UAE GCAA approved the operational use of the EFB system in the operator's Airbus aircraft in 2001, following a 6-month flight evaluation of the system by the operator in 2000 to 2001.

The GCAA Civil Aviation Advisory Publication CAAP 18 *Electronic Flight Bag (EFB)* of 1 March 2004 provided information on, and GCAA policy regarding the certification, airworthiness, and operational approval for the use of EFBs by operators in the UAE. It described the EFB hardware classes and the software applications, human factors and risk mitigation considerations, the operational approval process, and aspects to be considered during regulatory surveillance of the system. That document was issued after the approval of the operator's EFB.

### **2.3.4 EFB database revision**

The EFB database was updated as part of a monthly revision process after review by a flight operations engineer before being approved by the Manager Flight Operations Technical Development. Aircraft EFBs were then individually updated.

Both of the EFBs that were carried on the accident flight contained software version 9.3 with a database dated 12 March 2009, which was the current version.

### **2.3.5 EFB training program**

Initial training on the EFB was conducted by the operator's Flight Operations Training section during their A330 aircraft performance course. That included the operation of the EFB and extracting information from the flight plan and loadsheet to calculate the take-off performance data. The training also included a review of the *Takeoff Performance Error Check* and the *Loadsheet Confirmation Procedure* SOPs.

The EFB training included practice using the equipment itself and a written examination comprised of a series of questions relating to calculating the: optimum aircraft configuration, take-off speeds, maximum take-off weight; and the flexible temperature for thrust reduction on a variety of runway surfaces. A copy of the completed examination was held on an individual pilot's training file.

To gain a type rating on the A340-300 and A340-500, flight crew attended a training course that included the differences in aircraft performance between the A330 and A340, and the use of the EFB to calculate take-off performance on the A340 aircraft type.

The operating captain and first officer had received classroom training on the EFB and manual calculations. Both reported that they routinely used the EFB in normal line operations and rarely conducted a manual calculation. The captain and the first officer stated that they did not find the EFB difficult to use.

### **2.3.6 EFB guidance material**

The FCOM contained guidance material relating to the EFB take-off performance module. It described the EFB screen format, the method of entering data, the means to initiate the data computation, and the format of the result grid.

### **2.3.7 Obtaining take-off performance data from the EFB**

To calculate take-off performance data, the take-off performance module was opened in the EFB and the desired runway selected from the database ① (Figure 27). The wind speed and direction ②, outside air temperature ③, altimeter setting (QNH) ④, proposed take-off weight ⑤, flap configuration ⑥,<sup>39</sup> air conditioning status ⑦, anti-ice selection ⑧, runway surface condition ⑨, and aircraft centre of gravity position ⑩ were entered into the EFB.

Selection of the COMPUTATION button calculated the take-off performance data and displayed the following:

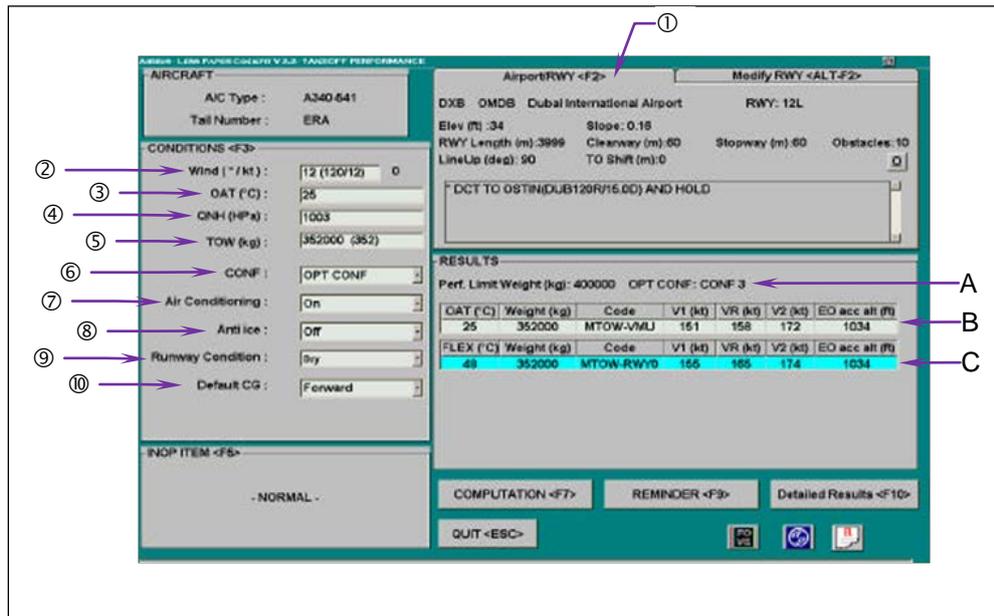
- Performance-limited take-off weight<sup>40</sup> and optimum flap configuration for the selected runway and entered conditions (A).
- Take-off speeds and the engine-out acceleration altitude for the proposed take-off weight using full take-off thrust at the actual outside air temperature (B).
- Take-off speeds and the engine-out acceleration altitude for the proposed take-off weight using less than full take-off thrust based on a computed FLEX take-off thrust temperature value (°C).

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<sup>39</sup> The OPT CONF, or optimum configuration was normally used. This setting allowed the computation of the optimum aircraft configuration for takeoff. The optimum configuration gave the lowest take-off speeds.

<sup>40</sup> The highest weight possible for the takeoff based on the actual conditions.

Figure 27: EFB take-off performance screen



Source: A340-500 FCOM Vol 2

Note: Example shown for illustration only and does not contain data from the accident flight.

To display the data in a format that resembled the FMGS MCDU take-off page (Figure 28), the REMINDER button was selected. This data was equivalent to that displayed at position (C) on the previous screen.

Figure 28: EFB take-off performance screen with FMGS format



Source: A340-500 FCOM Vol 2

Note: Example shown for illustration only and does not contain data from the accident flight.

## 2.4 Inconsistencies within the take-off performance planning documentation

The following inconsistencies were identified during a review of the operational documentation relating to the calculation and checking of the take-off performance parameters.

The FCOM section *Standard Operating Procedures Cockpit Preparation*, described the Takeoff Performance Error Check and Data Entry Confirmation Check (section 3.03.06 page 17A, see Appendix E). Both of those procedure items referred to the Briefing Guide in section 3.03.91, page 4 of the FCOM, which provided an example of the verbal communications associated with those checks. The guide included an additional item after the *Data Entry Confirmation* example which stipulated that captains were required to transcribe the result take-off weight and green dot speed onto their copy of the flight plan. This additional item was not included in the main procedure in section 3.03.06.

The procedure in the briefing guide for recording the green dot speed on the captain's flight plan, also noted that the captain shall obtain that value from either the QRH or the LPC (EFB). The investigation found that obtaining the green dot speed from the QRH would not detect a weight error in the EFB during the loadsheet confirmation procedure when the correct TOW was used as the reference in the QRH. That is, the green dot speed from the EFB was not being crosschecked against the FMGS, meaning that the TOW used in the EFB calculation was not being checked.

The loadsheet confirmation procedure in FCOM (section 3.03.07 page 1, Appendix E) did not contain detail of what the loadsheet confirmation procedure entailed, other than what the first officer was required to record on the master flight plan, and referred pilots to the Briefing Guide in section 3.03.91. That guide did not explicitly state what was required of the checks, but provided an example of what communications should occur between crew members. The guide also included items that preceded the loadsheet confirmation procedure (that was, the Loadsheets Data and Take-off Data checks), even though the briefing guide was not referred to by those procedures.

Both operating flight crew reported that the briefing guide was 'only advisory information'.

The FCTM *Supplementary Normal Operations* provided information about the take-off performance calculation and checking process in both tabular and flowchart form, but did not include any reference to recording of the green dot speed or its use in the Loadsheets Confirmation Procedure 'Gross Error Check'.

## 2.5 Cross crew qualification and mixed fleet flying

### 2.5.1 Overview

Cross crew qualification (CCQ) was a training program implemented by the aircraft operator that was based on:

...a reduced type rating<sup>[41]</sup> transition course which gives credit for the technical similarities and common operational and handling procedures. The term CCQ is reserved for such courses between Airbus fly-by-wire types.<sup>[42]</sup>

The CCQ program enabled an aircraft operator who had trained flight crew to a full type rating on one aircraft type (the base aircraft)<sup>43</sup> to then, after a qualifying period, permit the flight crew to undergo reduced type-training courses to gain full ratings on other aircraft types/variants.<sup>44</sup> The other aircraft types or variants were required to have a high level of commonality in handling characteristics, a similar cockpit environment and operational philosophy, and similar procedures and checklists as the base aircraft. As a result, significant reduction in the systems training, flight simulator training, and initial operating experience requirements for the type rating on the other aircraft types was permitted.

Mixed fleet flying (MFF) was defined as:

... the operation of a base aircraft and one or more variants of the same type, common type, related type, or a different type<sup>[45]</sup> by one or more flight crew members, between training or checking events.<sup>[46]</sup>

MFF operations enabled an aircraft operator to schedule CCQ-trained flight crew to fly more than one type and/or variant of aircraft within a single duty period or between proficiency checks. The regulatory authority overseeing a particular operator may develop specific criteria limiting the number of different aircraft types or variants that can be flown during a single duty period.

Since 1996, a number of airline operators worldwide have implemented CCQ training programs and introduced MFF operations across their Airbus A330 and A340 fleets.

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<sup>41</sup> A type rating is an endorsement on a flight crew licence that signifies that the licence holder has successfully completed an authorised minimum systems knowledge and flying skills training program that permits the holder to operate a specific aircraft type.

<sup>42</sup> Joint Aviation Authorities Joint Operation Evaluation Board, *JAA JOEB Report Airbus A320 - A330 – A340 CCQ & MFF*, 12 March 2004.

<sup>43</sup> The aircraft, or a group of aircraft, designated by the aircraft operator and used as a reference to compare differences from other aircraft types/variants within the operator's fleet.

<sup>44</sup> An aircraft, or a group of aircraft, with the same characteristics but that have pertinent differences from a base aircraft. Pertinent differences are those differences that require additional flight crew knowledge, skills, and or abilities that affect flight safety.

<sup>45</sup> Two or more aircraft that have different type ratings for which simulator training is mandatory (e.g. A330/A340).

<sup>46</sup> Airbus SAS, Document AI/ST-SV-CA, *Mixed Fleet Flying A330 – A340, Airbus Recommendations*, April 2004.

## 2.5.2 Regulatory requirements

UAE GCAA CAR-OPS 1.980 *Operation on more than one type or variant* outlined the requirements for CCQ training and MFF operations. The CAR included the requirements that the:

- operator ensure that flight crew members were competent to operate on more than one aircraft type or variant
- operator ensure that the differences and/or similarities of the aircraft involved in operations of more than one type or variant justify such operations, taking account of the level of technology, operational procedures and handling characteristics
- GCAA approve all training, checking, and recent experience requirements in relation to operations of more than one type or variant
- operator specify appropriate procedures and/or operational restrictions for operations of more than one type or variant covering flight crew minimum experience levels, the process for training and qualifying flight crew on another type or variant, and the recent experience requirements for each type or variant.

The above requirements were identical to the provisions of JAA JAR-OPS 1.980 *Operation on more than one type or variant*.

The UAE GCAA CARs and supporting documentation had no specific guidance on human factors considerations relating to flight crew being exposed to wide variations in take-off weights and associated take-off performance parameters during MFF operations.

## 2.5.3 Operator's requirements

The operator's requirements for CCQ training and MFF operations were defined in chapter 3 of its FOM. Flight crew were required to have completed 3 months and 150 hours flying, including a proficiency check, on the Airbus A330-243 (the 'base' aircraft) to be eligible for the CCQ training program. In addition, and based on flight crews' performance on the base aircraft, the operator's fleet managers were required to assess the competency of the flight crew selected for CCQ in relation to their ability to maintain MFF standards.

In order to be scheduled for MFF operations, crew members were required to have completed two consecutive operator proficiency checks and have 500 hours in the relevant crew role with the operator. To maintain the MFF qualification, flight crew were required to have completed, as the handling pilot, three takeoffs and three landings in either aircraft type (A330/A340) in the last 90 days, provided that at least one sector was conducted in each type.

Volume 3 of the operator's *A340-500 Flight Crew Operating Manual* required a crew, on first entering an A340-541 aircraft in preparation for a flight, to review the A340-500 technical and operational differences from the other aircraft in the operator's Airbus fleet. There was no consideration of a 'reasonableness' check of the take-off performance data.

## 2.6 Distraction management

A review of the operator's flight operations documentation did not find any reference to distraction or its management, other than in the Crew Resource Management Manual in relation to situational awareness. That manual stated a number of techniques for better situational awareness management, including that crews should:

Develop a plan and assign responsibilities for handling problems and distractions.

The FOM did contain a section on crew cooperation within the section on flight crew duties and responsibilities. That section noted, amongst other things, that all flight crew shall:

Co-operate with all other personnel involved with the actual flight, such as the ground staff, in order to comply with the Company operating policy.

There were no items in the training syllabus that related to the flight crew's management of distraction.

The operator reported that they had become aware of the problem of distraction during the pre-departure phase several months prior to the accident and had begun addressing the issue. That included a series of briefings to flight crew and the development of a plan to implement distraction management training for captains. The planning for that training program was still in progress and had not been implemented prior to the accident.

## 2.7 Fatigue management

The UAE GCAA had approved the flight and duty limitations specified in the operator's *Flight Operations Manual*, including a maximum limitation on flying time of 100 hours in a 28-day period. At the commencement of the duty period for the accident flight, none of the flight crew members exceeded the 100 hour flying time limitation.

### 2.7.1 Ultra Long Range operations

The operator's conduct of Ultra Long Range (ULR) operations followed the guidance published in UAE GCAA CAAP 14, *ULR Operations*.<sup>47</sup> That guidance included the recommendation that operators implement a Fatigue Risk Management System (FRMS) for ULR operations.

The use of an FRMS to counter the risk of fatigue in the aviation industry has been increasing. Aviation regulators in the United Kingdom, Canada, New Zealand and Australia have encouraged the implementation of these systems either in partnership with prescriptive regulatory requirements, or as an alternative to those requirements. At the time of writing, the International Civil Aviation Organization was developing standards and recommended practices for FRMS.

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<sup>47</sup> The CAAP defined an ULR operation as 'An operation involving any sector between a specific city pair (Point A - Point B - Point A) where the scheduled flight time could exceed 16 hours at any time during a calendar year taking into account the mean and seasonal wind changes'.

The operator included a FRMS as part of their ULR operating procedures that were approved by the UAE GCAA. The investigation assessed the operator's FRMS using the validation process recommended by the Flight Safety Foundation for a ULR FRMS operational model.<sup>48</sup> That assessment showed that the operator's FRMS contained all of the elements recommended for a ULR FRMS.

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<sup>48</sup> Flight Safety Foundation (2005). Fourth workshop yields insights into early ultra-long-range flight experience. *Lessons from the dawn of ultra-long-range flight*. Flight Safety Digest August-September 2005, Flight Safety Foundation.

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## 3 FACTUAL INFORMATION: HUMAN FACTORS

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Human factors is the multi-disciplinary science that applies knowledge about the capabilities and limitations of human performance to all aspects of the design, operation and maintenance of products and systems. It considers the effects of physical, psychological and environmental factors on human performance in different task environments, including the role of human operators in complex systems.

The following information is intended to provide a context for the actions of the flight crew, and factors affecting them, on the night of the accident.

### 3.1 Error formation

Human error has been defined as ‘the failure of planned actions to achieve their desired ends – without the intervention of some unforeseeable event.’<sup>49</sup> The following sections describe how human errors can be formed and what contributes to their progression through the systems intended to capture them.

#### 3.1.1 Data entry and transposition errors

A common type of data entry error is known as a *slip*. A slip is an error in the execution of an action,<sup>49</sup> for example, a slip of the tongue or ‘finger trouble’, such as hitting the wrong key when typing. Slips are externally observable actions that are not as the individual intended.

Slips are generally related to skill-based activities. That is, actions that have become so rehearsed and automatic that the individual does not need to closely monitor each stage of the action sequence in the way that they would if the task were less familiar or unknown. Due to this reduced monitoring, the individual will generally not realise that they have carried out an incorrect action until it is either too late to change, or there has already been an unforeseen consequence.

A *transposition error* occurs when an individual inadvertently swaps two adjacent numbers or letters while speaking or writing down a value or word. For example, writing down 132 instead of 123, or saying ‘ACB’ instead of ‘ABC’ during a conversation. In aviation, this may occur when reading back the aircraft call sign to ATC or when recording a numerical value, such as a fuel figure or an assigned heading, altitude or radio frequency.

### 3.2 Error detection

Various studies have shown that a significant number of errors made by individuals are detected only when it is too late for effective intervention and recovery. A study by Sarter and Alexander in 2000 examined error types and detection mechanisms and found that ‘the majority of slips and lapses in our database [US Aviation Safety

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<sup>49</sup> Reason, J. (1990). *Human Error*. Cambridge University Press, Cambridge, United Kingdom.

Reporting System] involved attentional problems' with slips most often relating to 'competing demands in high-tempo operations'..<sup>50</sup>

When it came to detecting errors, the same authors found that routine checks were the most frequently successful detection technique for errors of omission. Errors of omission, that is, a failure to do something that should have been done, relied on routine checks and therefore took longer to detect, and in some cases resulted in a violation.<sup>51</sup> or other unintended outcome. However, slips were more likely to be detected based on routine or 'suspicious' checks, wherein crew suspected a problem and went looking for it, or on an observed outcome of the slip. The authors noted that, when they were detected, slips were more likely to be identified by the person who made them.

In a 2004 observational study of airline operations by Thomas, Petrilli and Dawson, that was designed to assess error detection and recovery, noted that 'less than half the errors committed by crews were actually detected'..<sup>52</sup> In addition, it was found that 'error detection is more easily accomplished by the crewmember who was not responsible for the error'. While this appears to be the opposite of the findings by Sarter and Alexander, it should be noted that their study used self-reported data, and that the crew must therefore have been aware of the error in order to report it. That study found that slips were more likely to be noticed by the crewmember that made them, whereas this study discussed errors in general, which may not be comprised only of slips. The observational study also found that systemic defences such as checklists detected only 0.8% of errors.

Another observational study by Thomas in 2004 examined threat and error management during different phases of flight..<sup>53</sup> The study found that the majority of errors occurred during pre-departure, takeoff, and descent-approach-landing. Those results were consistent with another finding of the study: that the majority of threats are found during the pre-departure and descent-approach-landing phases of flight.

### 3.3 Distraction and interruptions

Research in the area of distraction and interruptions in the cockpit has involved gathering data during observations of normal operations with researchers seated in aircraft cockpits and noting crew activities, actions, and interactions with external parties including ground staff, cabin crew, and ATC.

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<sup>50</sup> Sarter, N.B. & Alexander, H.M. (2000). Error types and related error detection mechanisms in the aviation domain: an analysis of aviation safety reporting system incident reports. *The International Journal of Aviation Psychology* 10(2), 189-206.

<sup>51</sup> Violations can be defined as deliberate – but not necessarily reprehensible – deviations from those practices deemed necessary to main the safe operation of a potentially hazardous system. Reason, J. (1990). *Human Error*. Cambridge University Press, Cambridge, United Kingdom.

<sup>52</sup> Thomas, M.J.W., Petrilli, R.M. & Dawson, D. (2004). *An exploratory study of error detection processes during normal line operations*. In Proceedings of the 26<sup>th</sup> conference of the European Association for Aviation Psychology. Lisbon, Portugal 2004.

<sup>53</sup> Thomas, M.J.W. (2004). Predictors of threat and error management: identification of core nontechnical skills and implications for training system design. *The International Journal of Aviation Psychology* 14(2) 207-231.

In a study by the US National Aeronautics and Space Administration (NASA) Ames Research Centre in 2001, researchers conducted in excess of 60 observation flights and commented on task activity, distraction, and interruptions in the cockpit.<sup>54</sup> The researchers noted that the events that distracted and interrupted flight crew were ‘numerous and varied’. Related was the need for flight crew to make decisions regarding those interruptions, which may impact the scheduling and action of other tasks. The authors found that ‘opportunities for errors increase dramatically as distractions continuously threaten to sidetrack even the most meticulous and experienced pilot’. Of particular interest to the accident flight was the finding that ‘the flight deck [cockpit] is rarely ever sterile and devoid of distractions’.

Distractions and interruptions, and how flight crew manage them, have ramifications for the design of tasks and checklists. As part of the same broad NASA study, training and procedures were reviewed to assess the extent to which they correlated with what the researchers observed in flight. The researchers found that ‘procedures and classroom training ... give almost no indication of the substantial concurrent task demands we observed’<sup>55</sup> and that the ‘procedures and training are misleading in three respects: they give the impression that the procedures are linear, that the pilots have full control of their execution, and that the procedures flow uninterruptedly’. With regard to training in this area, the authors noted that ‘the haphazard arrival of paperwork on the line is poorly, if at all, captured in simulator training’.

One of the operator’s first officers, who was also a simulator training first officer, reported that simulator sessions were conducted without distraction or interruptions being introduced by the instructor.

Specific research into the disruptive effect of interruptions and the effect of those interruptions on task resumption has found that people may ‘think they have completed the step, and upon resumption actually skip that step’ and that ‘in some workplace situations, the primary task is never actually resumed’.<sup>56</sup> A further study that was referenced in the Trafton and Monk article, found that ‘high-priority, complex tasks...were negatively impacted the most by interruptions... [and] that it is quite difficult to return to these complex tasks’.<sup>57</sup>

The authors of the 2001 NASA study also discussed in a second study the implication of interruptions and distractions during monitoring tasks, including the

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<sup>54</sup> Loukopoulos, L.D., Dismukes, R.K. & Barshi, I. (2001). *Cockpit interruptions and distractions: A line observation study*. In Proceedings of the 11<sup>th</sup> International Symposium on Aviation Psychology, Columbus, OH, The Ohio State University, March 2001.

<sup>55</sup> Loukopoulos, L.D., Dismukes, R.K. & Barshi, I. (2003). *Concurrent task demands in the cockpit: challenges and vulnerabilities in routine flight operations*. In Proceedings of the 12<sup>th</sup> International Symposium on Aviation Psychology, Columbus, OH, 14-17 April 2003.

<sup>56</sup> Trafton, J.G. & Monk, C.A. (2008). *Task Interruptions* in Reviews of Human Factors and Ergonomics, volume 3, Human Factors and Ergonomics Society.

<sup>57</sup> Czerwinski, M. P., Horvitz, E., & Wilhite, S. (2004). Cited in Trafton, J.G. & Monk, C.A. (2008). *Task Interruptions* in Reviews of Human Factors and Ergonomics, volume 3, Human Factors and Ergonomics Society.

cognitive demands in a monitoring role.<sup>58</sup> The authors highlighted the challenge of monitoring a system for an unexpected and untoward event, something ‘... at which humans are notoriously poor’.

Another study into concurrent and deferred tasks found that, despite numerous incidents and accidents being a function of excessive workload, there was often sufficient time for all essential tasks to be completed. They concluded that the issue ‘... seems to be how well pilots can manage attention to keep track of concurrent tasks without becoming preoccupied’.<sup>59</sup> This finding is of relevance to this occurrence, given that the operating crew completed the pre-departure procedures and associated tasks several minutes before the scheduled departure time.

The use of checklists in aviation was reviewed in another study, which found that checklists were often not properly completed.<sup>60</sup> Numerous reasons were given for this, including the fact that the cockpit was extremely busy with various sources of information competing for attention.

Research conducted in 2001 focused on determining the effect of extraneous sound on flight crew performance.<sup>61</sup> The results of that research showed that ‘... memory for [the task] was severely disrupted when extraneous background speech was presented concurrently’ and ‘... the presence of background speech disrupts performance on this task, despite participants trying to ignore it’.

Research on the impact of distraction and interruptions in the cockpit, specifically during pre-departure, and on the use of checklists has particular relevance to the accident flight. Distraction and interruptions have been identified in previous data entry occurrences as an influence on either the error itself or non-detection of the error.

The operating captain reported that when he first became a captain he was ‘strict and disciplined’ regarding distractions. He also noted that he had ‘drifted’ from that approach, especially at the operator’s home base because the ground staff continued to interrupt the flight crew despite being instructed by the operator to not do so. The captain considered that he was no longer as strict about managing ground crew interactions as he had been originally.

### 3.4 Prospective memory

Closely linked to distraction, interruption and task resumption is a topic of memory known as *prospective memory*. Prospective memory can be defined as the intention

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<sup>58</sup> Loukopoulos, L.D., Dismukes, R.K. & Barshi, I. (2003). *Concurrent task demands in the cockpit: challenges and vulnerabilities in routine flight operations*. In Proceedings of the 12<sup>th</sup> International Symposium on Aviation Psychology, Columbus, OH, 14-17 April 2003.

<sup>59</sup> Dismukes, R.K., Loukopoulos, L.D. & Jobe, K.K. (2001). *The challenges of managing concurrent and deferred tasks*. In Proceedings of the 11<sup>th</sup> International Symposium on Aviation Psychology, Columbus, OH: The Ohio State University, March 2001.

<sup>60</sup> Diez, M., Boehm-Davis, D.A. & Holt, R.W. (2002). *Model-based predictions of interrupted checklists*. In Proceedings of the Human Factors and Ergonomics Society 46<sup>th</sup> Annual Meeting – 2002, 250-254.

<sup>61</sup> Banbury, S.P., Macken, W.J., Tremblay, S. & Jones, D.M. (2001). Auditory distraction and short-term memory: Phenomena and practical implications. *Human Factors* 43(1), 12-29.

to perform an action in the future, coupled with a delay between recognising the need for the action and the opportunity to perform it.<sup>62</sup> A distinguishing feature of prospective memory is the need for an individual to remember that they need to remember something. As highlighted in that study, ‘the critical issue in prospective memory is...retrieval of...intentions at the appropriate moment, which is quite vulnerable to failure’. This is reinforced by a study of US self-reported incident data referred to in Dismukes’ paper, which found that 74 out of 75 incident reports made by airline flight crew involved a failure of prospective memory.

Prospective memory can create problems when used concurrently with habitual tasks, which ordinarily occur quite reliably both in aviation and everyday life. Problems can occur when the cues used by flight crew to perform habitual tasks are removed. For example, when items on a checklist are delayed or conducted out of sequence, thereby removing the habitual links between tasks that are usually conducted in a particular, unbroken sequence.

This is particularly relevant when flight crew are interrupted and need to resume a task. They then rely on prospective memory and, in many cases, have no cues in the cockpit to indicate where they were at the time of the interruption. Studies have shown that people often fail to resume a task when interrupted if their attention is quickly diverted to a new task before they can resume the interrupted task.

### 3.5 Inattentional blindness and expectancy

Inattentional blindness, or the ‘looked-but-failed-to-see-effect’<sup>63</sup>, is a failure to perceive what would appear to others as an obvious visual stimulus. This occurs when an individual’s attention is engaged on another task and does not necessarily mean an individual was ‘not paying attention’ but that the individual’s attentional resources were occupied elsewhere. All individuals have limited attentional resources, so it is possible to miss vital visual stimuli if attention is allocated to another task.

Research on human information processing suggests that inattentional blindness can be influenced by workload, expectation, conspicuity and capacity.

Expectancy is another factor that can influence the visual system, including how and where people look for information. The six factors identified by Wickens and McCarley that affect the visual system are:<sup>63</sup>

- habit
- salience
- event rate (the more frequently an event happens in an area the more individuals will look at this area)
- contextual relevance (individuals look at something they believe has relevant information there)

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<sup>62</sup> Dismukes, K. (2006). *Concurrent task management and prospective memory: pilot error as a model for the vulnerability of experts*. In Proceedings of the Human Factors and Ergonomics Society 50<sup>th</sup> Annual Meeting – 2006, 909-913.

<sup>63</sup> Wickens, C.D. & McCarley, J.S. (2008). *Applied attention theory*. CRC Press, Boca Raton, FL, United States of America.

- information value (individuals look at something as it has intrinsic value to them)
- effort conservation.

Habit, event rate, and contextual relevance can be affected by an individual's expectancy. As a result, an individual's visual scanning can be influenced by their expectancy. For example, an expectation by a crewmember that any data entry error occurring during the use of an EFB will happen in the last four digits may lead them to check only those digits and not the whole number. This may increase the potential for crew to only check areas where they have found problems previously, or information that is readily and easily presented.

Expectancy can influence flight crew's ability to detect errors when conducting checks of a system. The crew may search for errors in the system in accordance with standard operating procedures, but not detect them because they are 'looking but not seeing' the items being checked. This highlights the difference between automatically 'checking' something and verifying its accuracy. To check a value, an individual may look at it but not be able to verify its relevance or accuracy – that is, 'see' the number, but not notice the error. For example, verifying the accuracy of a value in an EFB may involve actively re-calculating it, rather than passively 'checking' it by comparing the entry against the corresponding value from a different source.

## 3.6 Interaction with automation

Cockpit automation has been increasing since the 1980s and has influenced the way pilots interact with aircraft systems. Various studies into this interaction have been conducted in order to inform system design and to understand human limitations within this setting.<sup>64, 65, 66</sup>

Recent studies have focused on information searching and problem diagnosis within an automated cockpit. One such study found that automated systems were bringing 'cues from the outside environment into the cockpit and displaying them as highly reliable and accurate data' thereby engineering out any uncertainty that would normally have existed.<sup>67</sup> However, the use of that data is affected by how flight crew identify what information is accurate and relevant, and how they interpret the information to make a decision. As noted by the authors of that study, 'Many pilot errors ... involve a failure to note or analyse important information in the electronic "story" that is not consistent with the rest of the picture'.

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<sup>64</sup> Lyall, B. & Funk, K. (1998). *Flight deck automation issues*. In M.W. Scerbo & M. Mouloua (Eds.) Proceedings of the Third Conference on Automation Technology and Human Performance held in Norfolk, VA, March 25-28, 1998. (pp. 288-292). Mahwah, NJ: Lawrence Erlbaum Associates.

<sup>65</sup> Christoffersen, K. & Woods, D.D. (2002). *How to make automated systems team players*. In Advances in Human Performance and Cognitive Engineering Research, Vol 2, p 1-12. Elsevier Science Ltd.

<sup>66</sup> Endsley, M.R. & Kiris, E.O. (1995). The out-of-the-loop Performance Problem and Level of Control in Automation. *Human Factors* 37 (2) 381-394.

<sup>67</sup> Mosier, K.L., Sethi, N., McCauley, S., Khoo, L. & Orasanu, J.M. (2007). What you don't know can hurt you: factors impacting diagnosis in the automated cockpit. *Human Factors* 49 (2), 300-310.

The study identified that ‘pilots may be inclined to use the most salient information source – typically an automated indication’ and that ‘airline policies may promote dependence on automated displays and discourage taking the time to analyse them carefully or verify them by checking other data sources’. This highlights a potential problem in that flight crew may seek to only look at the automated source and rely on this to the exclusion of other data sources and, as such, may not detect discrepancies or inconsistent data. Previous studies identified a tendency for flight crew to ‘see information they expected to see rather than what was there’, which could be viewed as a form of expectancy that was based upon their experience of what the automation normally displayed.

In addition, a simulator study of flight crew found that ‘even when scanning included the [instrument being monitored], pilots failed to understand the implications [of what they were seeing]’..<sup>68</sup> That is, the pilots had a view that the results being presented by automation were accurate and often failed to understand that this may not always be the case. This is of particular relevance to the accident flight as the captain reported that, in his experience, the EFB figures were ‘always right’.

A function of automated systems in aviation is that they are generally highly complex and highly reliable. A study in 2002 examined the performance of highly skilled flight crew in a high-fidelity simulator to gain an understanding of the use of automation. The authors found that ‘monitoring failures constitute a major contributor to breakdowns in pilot-automation interaction ... [and] that pilots do not always respond appropriately to unanticipated changes in automation ... because of the high level of complexity and coupling of modern flight deck technologies’..<sup>69</sup>

Systems such as EFBs are examples of complex and coupled technology where the EFB calculation process is not readily apparent to the flight crew. To obtain performance parameters, the flight crew need only input the required data, such as ambient conditions, and then record the results.

This is relevant to the accident flight because the operating flight crew reported feeling ‘out of the loop’ when using the EFB to calculate take-off performance parameters, and that they had a high level of trust in the results from the EFB.

The operating first officer reported that, during his initial flight training and flying prior to joining the operator, he used imperial instead of metric values, and had adjusted to using metric values in the time he had been flying with the operator. However, he felt he still did not have the same ease of comprehension of the figures that he would have had if they were imperial values.

### 3.7 Checklist design and use

Checklists are used in airline operations to ensure that critical actions are performed as and when necessary during each phase of flight. Checklists are normally

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<sup>68</sup> Mumaw, R.J., Sarter, N.B. & Wickens, C.D. (2001). *Analysis of pilots’ monitoring and performance on an automated flight deck*. In proceedings of the 11<sup>th</sup> International Symposium on Aviation Psychology. Columbus, OH: The Ohio State University, March 2001.

<sup>69</sup> Sarter, N.B., Mumaw, R.J. & Wickens, C.D. (2007). Pilots’ monitoring strategies and performance on automated flight decks: an empirical study combining behavioural and eye-tracking data. *Human Factors* 49 (3) 347-257.

designed as ‘challenge-response’ items. That is, the pilot(s) set up the cockpit as necessary and then check that all actions have been completed correctly. To do this, one pilot calls the action or setting and the other confirms its completion. Given that checklists are used for every flight, pilots become very familiar with the required actions and responses.

During observation flights looking at the use of checklists, one study found that ‘often, the pilot...would answer with the proper response immediately when he/she heard the challenge call from the [other] pilot, not verifying that the item called was set accordingly’..<sup>70</sup> The study also found that the use of ambiguous terms in a checklist affected the use of the checklist by pilots. The continued use of ‘checked’ or ‘set’ instead of reading out what was being seen, for example ‘airspeed set 125’, will make it easier for pilots to respond to a checklist item without actually verifying what it is they are checking.

### **3.8 Potential for error in take-off performance calculation**

The introduction of EFBs for take-off performance calculations replaced the manual process, which required the use of paper-based charts and tables. This resulted in a reduction in the number of steps flight crew used to determine the performance parameters, and hence the opportunities for error. However, the use of an EFB has not eliminated error potential, it has resulted in a range of error types primarily relating to data entry errors and in the misreading of the results. Those error types can include transcription errors, keystroke errors, and the selection/calculation of incorrect data.

### **3.9 Flight crew experience in the detection of erroneous take-off performance parameters**

The captain and first officer reported that, during their time with the operator, they had observed the checks that were embedded in the operator’s SOPs detect EFB data entry errors. Both crewmembers reported that certain errors were more likely than others, such as entering the block fuel incorrectly or entering incorrect ambient conditions and aircraft configuration.

The first officer reported that most of the take-off weight errors that he had encountered were the result of errors made when adding the allowance for last minute changes, or in small changes in the block fuel. Both resulted in differences to the right side of the weight value. The first officer noted that his attention was normally drawn to the right side of the weight numeral group to check for those types of error.

Both flight crew reported that, prior to the accident, they believed any error in the use of the EFB would be detected by another crewmember during subsequent checks during the pre-departure activities. They reported that their experience in detecting errors, and the reliance on the EFB in normal operations, meant that they had a high level of trust in the calculation and checking process.

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<sup>70</sup> Degani, A., & Wiener, E. L. (1993). Cockpit checklists: Concepts, design and use. *Human Factors*, 35(2), 345-359.

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## 4 FACTUAL INFORMATION: TAKE-OFF PERFORMANCE

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This section, provides an overview of the take-off performance aspects used in civil transport operations. The section will discuss the philosophy used in general and for reduced thrust take-off operations, together with some of the human factors aspects relating to the perception of take-off performance.

### 4.1 Civil transport aircraft take-off performance philosophy

The underlying philosophy of civil transport aircraft take-off performance is that, in the event of the failure of one engine during takeoff, the aircraft can either safely take off or be stopped within the runway length (including any stopway). The take-off performance standards that incorporate the intent of this philosophy are contained in the US Title 14 Code of Federal Regulations *Aeronautics and Space Part 25 Airworthiness Standards: Transport Category Airplanes* and the European Joint Aviation Requirements JAR-25 *Large Aeroplanes*.<sup>71</sup>

In order to comply with these standards, flight crew need to ensure that for each flight the take-off distance required does not exceed the take-off distance available (runway length plus any available clearway). They also need to ensure that the accelerate-stop distance required does not exceed the accelerate-stop distance available (runway length plus any available stopway). As part of this process, the flight crew determine a set of take-off reference speeds:<sup>72</sup>

- V<sub>1</sub> Decision speed, the maximum speed at which a rejected takeoff can be initiated by the pilot, and the minimum speed at which the takeoff can be continued in the event of an engine failure. If an engine failure does occur after V<sub>1</sub>, the takeoff should be continued.
- V<sub>R</sub> Rotation speed, the speed at which the aircraft rotation is initiated by the pilot. This speed ensures that, in the event of an engine failure, lift-off is achievable and the take-off safety speed (V<sub>2</sub>) is reached at 35 ft above ground level at the latest.
- V<sub>2</sub> Take-off safety speed, the minimum speed that needs to be maintained up to the acceleration altitude, in the event of an engine failure after V<sub>1</sub>. Flight at V<sub>2</sub> ensures that the minimum climb gradient required is achieved, and that the aircraft is controllable.

The distances at which those speeds occur along the runway are a function of the acceleration of the aircraft, which is proportional to the aircraft's weight and the applied engine thrust.

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<sup>71</sup> JAR-25 has been replaced with Certification Specifications CS-25 since the establishment of EASA.

<sup>72</sup> Airbus (2004), *Flight Operations Briefing Notes – Takeoff and Departure Operations, Understanding Takeoff Speeds*. Airbus Customer Services.

## 4.2 Reduced thrust takeoff philosophy and procedure

Aircraft are certified to a minimum performance standard during takeoff to ensure the safety of operations. To allow operations from a variety of airports and to meet performance requirements under a variety of ambient conditions, many aircraft are capable of exceeding the minimum take-off performance standards. In such cases, the takeoff can be conducted at less than maximum available thrust and still meet the performance requirements. This procedure ‘... increases engine life and reliability, while reducing maintenance and operating costs.’<sup>73</sup> On Airbus aircraft, a reduced thrust takeoff is referred to as a FLEX (for flexible) takeoff.

The reduced thrust takeoff procedure has been used by operators since the 1960s and is common practice across the airline industry. Regulatory guidance about the procedure is provided in FAA Advisory Circular (AC) 25-13 and JAA Advisory Material Joint (AMJ) 25-13, both titled *Reduced and Derated Takeoff Thrust (Power) Procedures*. An aircraft’s FCOM provides certification and authorisation data in relation to reduced thrust takeoffs. Airline operators incorporate the procedure into their SOPs as required and the national regulatory authority grants approval to the operator to conduct reduced thrust takeoffs during scheduled operations.

The reduced thrust calculation determines a set of performance figures for the aircraft, including the take-off reference speeds and a calculated temperature that is referred to as the ‘assumed temperature’ (or FLEX temperature for Airbus aircraft). By using a higher temperature than ambient, the engine control system will reduce the amount of thrust the engines deliver, thereby reducing the wear on the engines. The FLEX temperature is calculated to ensure that the required take-off performance will be achieved for the aircraft weight and engine thrust available at that calculated temperature.

On the Airbus A340-541, the FLEX temperature is entered into the FMGS via the MCDU PERF TAKE OFF page (Figure 29). The FMGS provides the FLEX temperature to the full authority digital engine control (FADEC) systems. When the flight crew advance the thrust levers to the FLX/MCT.<sup>74</sup> position for takeoff, the FADECs determine and control the engine thrust setting according to the FLEX temperature.

When operating at a reduced thrust setting using a FLEX temperature for takeoff, the flight crew can, at any time, use the maximum rated takeoff (TO/GA) thrust by advancing the thrust levers to that position.

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<sup>73</sup> Airbus Flight Operations Support and line Assistance (2002). *Getting to grips with aircraft performance*. Airbus S.A.S., Blagnac, France.

<sup>74</sup> FLEX/Maximum Continuous Thrust. Refer to Appendix B.9.2 for further detail on thrust setting.

Figure 29: FMGS PERF TAKE OFF page



### 4.3 Determination of acceleration during the take-off roll

#### 4.3.1 Determination of the required acceleration

Flight crew calculate take-off reference speeds for their aircraft's take-off weight, take-off configuration, runway characteristics and ambient conditions. The underlying calculation of the take-off reference speeds is predicated on a specific acceleration but that acceleration information is not directly provided to the flight crew, neither during the calculation process nor as a resultant parameter.

The provision of acceleration information is not required under the current regulatory performance standards. Those standards assume that, as a minimum, the aircraft will actually accelerate at the rate inherent in the calculation of the take-off reference speeds.

#### 4.3.2 Determination of the actual acceleration

A crew's assessment of aircraft performance during the take-off roll is based on monitoring the airspeed to determine when  $V_1$  has been attained. Flight crew are not trained to monitor the distance travelled or time taken to attain that airspeed, nor is this information displayed in any way in the cockpit. The crew are therefore unable to objectively quantify the aircraft's acceleration between setting take-off thrust and the aircraft attaining  $V_1$ .

### 4.4 Take-off performance monitoring techniques

There have been a number of recommendations issued by international investigation agencies since 1971 regarding the development of take-off performance monitoring systems to assist flight crew in their decision making during the take-off roll (refer Appendix F). A number of organisations have also

examined automated methods for monitoring take-off performance, since as long ago as 1954..<sup>75</sup>

At the time of the accident, there was no means available to the flight crew to monitor the performance of the aircraft during the take-off roll. The safety of the takeoff relied on the accuracy of the take-off performance calculations and on the flight crew detecting any degraded performance during the take-off roll.

## 4.5 Tests and research

### 4.5.1 Take-off performance calculations

#### ***Accident flight scenarios***

Following the accident, the operator provided one of the EFBs that was on board the aircraft during the accident flight.

The investigation entered the ambient conditions of the day and take-off weights of 262.9 and 362.9 tonnes respectively into that EFB to calculate the take-off performance parameters. A summary of the results of those calculations is presented in Table 5.

**Table 5: EFB results summary**

Take-off Weight (tonnes)	Take-off reference speeds (kts)			Flex Temperature (°C)	Configuration of high lift devices. <sup>76</sup>	Green Dot Speed (kts)
	V <sub>1</sub>	V <sub>R</sub>	V <sub>2</sub>			
262.9	143	145	154	74	1+F	225
362.9	149	161	173	43	3	265

#### ***Expected take-off performance***

The aircraft manufacturer calculated the expected take-off performance for the aircraft when a take-off weight of 362.9 tonnes was used in the performance calculations on the EFB, but when the actual aircraft weight was 361.9 tonnes. The resulting take-off speeds and distances are presented in Table 6.

<sup>75</sup> Brown, A.P., and Abbasi, H. (2009). *Takeoff Performance Monitoring systems technology, certificability and operability status*. Flight Research Laboratory, Institute for Aerospace Research National Research Council, Canada.

<sup>76</sup> Refer to Appendix B.3 for information on the available high lift device configurations.

**Table 6: Expected take-off performance for correct weight calculation**

V <sub>1</sub>		V <sub>MU</sub> <sup>77</sup>		V <sub>R</sub>		V <sub>LOF</sub> <sup>78</sup>		V <sub>2</sub>	
Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)
149	1,710	160	2,010	161	2,065	174	2,540	173	2,470

In the above table, *Pos* is the position along the runway measured from the point at which the brakes were released. The actual take-off distances travelled on the accident flight were calculated from the FDR data for comparison and are listed in Table 7.

**Table 7: Actual take-off distances travelled on the accident flight**

V <sub>1</sub>		V <sub>MU</sub>		V <sub>R</sub>		V <sub>LOF</sub> <sup>79</sup>		V <sub>2</sub>	
Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)	Speed (kts)	Pos (m)
144	2,418	-	-	145	2,496	161	3,652	154	2,973

#### 4.5.2 Comparison of the A340-541 with the A330-243 and A340-313K

The crew operated on the A330-243, A340-313K and A340-541. Table 8 provides a comparison of some of the key aircraft specifications that affect its take-off performance.

**Table 8: A330 and A340 comparison**

	A330-243	A340-313K	A340-541
Maximum take-off weight (tonnes)	230	275	372
Maximum zero fuel weight (tonnes)	168	178	230
Number of engines	2	4	4
Engine thrust <sup>80</sup> (kN. each)	320	151	249

#### 4.5.3 Variability of take-off performance parameters

The flight crew reported observing a wide range of take-off performance parameters during normal operations as well as significant variations in passenger loads across routes and aircraft types. Both the captain and first officer reported that this resulted

<sup>77</sup> The minimum unstick speed. It is the calibrated minimum airspeed at which the aircraft can lift-off the ground and continue flight (Airbus, 2004).

<sup>78</sup> The speed at which the aircraft becomes airborne.

<sup>79</sup> The speed at which the FDR recorded the weight being off all wheels. For some time after, the tail was still in contact with the ground and supporting some of the aircraft's weight.

<sup>80</sup> At take-off/go-around (TO/GA) thrust.

in the take-off performance figures losing significance and becoming ‘just numbers’.

In order to examine the range of this variability, copies of the flight plans and load sheets for the 2 months prior to the accident were obtained from the operator for each of the four flight crew. There were 87 individual flights by the flight crew in that time. Considered representative of normal operations by the flight crew, that data is at Appendix G.

Only the ‘Master’ flight plan was supplied by the operator for that period because the captain’s copies were not archived. According to the operator’s SOPs, it was a requirement that the green dot speed be recorded by captains on their copy of the flight plan. It was found, however, that the green dot speed was often recorded either on the ‘Master’ flight plan or on the loadsheet. The nomenclature used and the location of the number written on those documents also varied significantly.

There was significant variation in the take-off performance parameters during the 2-month period examined, and the erroneous parameters used during the accident flight lay within the range of values observed during that period. Furthermore, the following points were noted:

- There was no direct correlation between an aircraft’s weight and the FLEX temperature.
- Although the take-off reference speeds generally increased with increasing weight, the variation was not linear and the correlation was very weak.
- The take-off reference speeds experienced by the crew varied by more than 50 kts.
- All four flight crew had experienced take-off parameters in the A340-541 that were very similar to the erroneous values used on the accident flight.

#### 4.5.4 Recorded acceleration data for A6-ERG

The information recorded by the FDR contained data for the aircraft’s previous three flights. The take-off weight and peak longitudinal acceleration for those and the accident flight are listed in Table 9.<sup>81</sup>

**Table 9: Recorded acceleration data for A6-ERG**

Sector	Take-off weight (tonnes)	Peak longitudinal acceleration (g)
Dubai to Melbourne	324.2	0.204
Melbourne to Auckland	246.3	0.317
Auckland to Melbourne	266.5	0.176
Melbourne to Melbourne (accident flight)	361.9	0.125

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<sup>81</sup> The crew on the accident flight were not involved in those previous flights.

## **4.6 Flight crew perception of the take-off acceleration during the accident flight**

All four flight crew reported that their perception of the aircraft's take-off acceleration was typical of a heavy A340, particularly a heavy A340-313K. The operating flight crew reported that they did not realise there was a problem with the aircraft's acceleration until they had nearly reached the end of the runway, and the red runway end lights became more prominent. Both operating flight crew reported that during operations from some runways at other airports, it was common to see the red runway end lights as the aircraft lifted off.



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## 5 FACTUAL INFORMATION: PRE-DEPARTURE PREPARATION AND TAKEOFF

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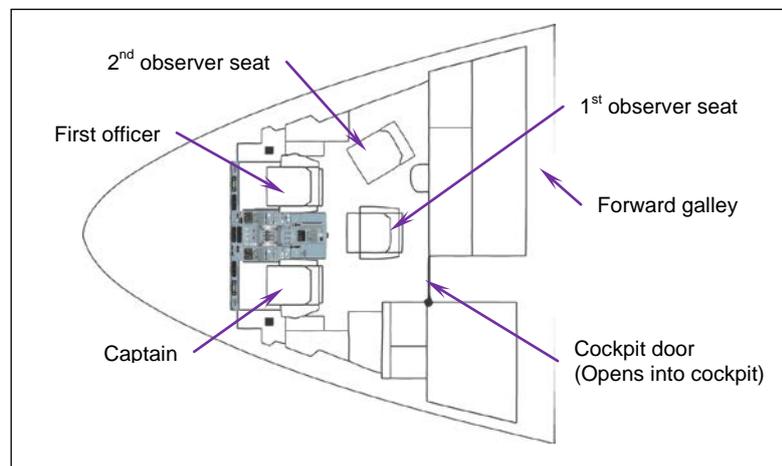
The following sequence of events contains information from the CVR, the ACARS, the flight plan, and interviews with the flight crew. Information presented in *italics* is explanatory, based on information from the interviews and other documentation obtained during the investigation. Items without time stamps indicate that the exact timing of that event could not be determined with accuracy, although they occurred in the sequence shown.

### 5.1 Pre-departure preparation

Following arrival at the airport, the first officer proceeded directly to the aircraft to prepare for the flight. The captain completed a number of other tasks before proceeding to the aircraft, and the augmenting flight crew remained with the cabin crew while they completed their pre-departure briefing. Following that briefing, the augmenting flight crew went to the cockpit to assist the operating flight crew with their preparations.

The augmenting captain then proceeded to the crew rest station to check the intercom while the augmenting first officer completed the external checks of the aircraft. On returning to the cockpit, the augmenting captain sat in the second observer's seat and the augmenting first officer waited in the forward galley because the ground engineers were in the cockpit and one was occupying the first observer seat (Figure 30).

**Figure 30: Cockpit arrangement**



Source: A340-500 FCOM Vol 1

Preparation for the flight included the initialisation and configuration of the aircraft's systems, and the entry and review of the flight plan in the navigation computers. At 2155, noticing that the first officer had not configured the overhead panel, the captain completed the required actions. Those actions included activating

the cockpit voice recorder (CVR).<sup>82</sup> A review of the CVR found that the take-off performance calculation and associated actions were captured by the recording.

The timing of, and actions during the pre-departure preparation are outlined in the following tabulated format.

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2127:30	The first officer initialised the FMGS.  <i>Initialisation of the FMGS resulted in a request being sent to the operator in Dubai, via the ACARS, to electronically upload the flight plan and associated data into the FMGS computers.</i>
	The first officer reviewed the uploaded flight plan data.  <i>As was normally the case, the upload did not include all of the information required by the FMGS for the flight and the crew were required to manually enter additional information. That information included, among other things, the aircraft weights, fuel load, and take-off performance data. Those items were entered as they became available.</i>
2137:20	The estimated zero fuel weight was sent by the operator to the aircraft via an ACARS message, annotated to note that it was 'flight closure data'  <i>The 'flight closure data' note indicated to the flight crew that the value was the final zero fuel weight, because all passengers had checked in, the baggage weight and cargo/mail load was finalised, and therefore the zero fuel weight would not change from that value.</i>
	The final fuel figures were determined by the flight crew.
2147	Refuelling of the aircraft was completed.
2147:11	The fuel figures report was sent by the captain to the operator in Dubai via ACARS to enable the completion of the loadsheet.  <i>The captain reported that he checked the flight plan in the FMGS and noticed that the first officer had selected the Nevis Four Standard Instrument Departure (SID).<sup>83</sup> and discussed with the first officer that they would likely be cleared via the Bison Three SID.</i>
2153:16	The loadsheet was sent from Dubai to the aircraft via ACARS.
2153:34	The loadsheet was printed on the cockpit printer.
2155:59	The captain configured the overhead panel.  <i>Those actions included the activation of the CVR.</i>

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<sup>82</sup> The CVR recorded the sounds on the flight deck and radio communications from 2155:59 until the aircraft had returned to Melbourne and the systems were shut down, a duration of almost 2 hours.

<sup>83</sup> A pre-planned, coded ATC instrument flight rules departure routing. Presented to flight crew in textual form, supplemented by graphics.

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2156:44 to 2157:22 The captain and the operator's ground engineers performed the fuel uplift check.

*The purpose of the fuel uplift check was to confirm that the fuel quantity loaded onto the aircraft matched the fuel quantity displayed on the cockpit fuel quantity indicating system. The fuel quantity loaded onto the aircraft was delivered in litres, and the aircraft fuel quantity indicating system displayed the fuel on board in kilograms. That required the captain to convert the delivered fuel quantity from litres to kilograms using the specific gravity of the fuel load.*

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2157:00 ATIS 'Uniform' was downloaded via ACARS.

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2157:34 to 2158:02 Food and beverages were delivered to the cockpit by the cabin crew.

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2158:08 The refuelling agent gave a copy of the fuel receipt to the captain and then left the cockpit.

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2158:19 ATIS 'Uniform' was printed on the cockpit printer.

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2158:34 to 2158:40 The captain checked with the first officer whether the ATIS was still 'Sierra'. The first officer informed him that it was now 'Uniform'.

The captain requested the pre-departure clearance (PDC).<sup>84</sup> from the operator in Dubai via ACARS.

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2158:57 The PDC was sent to the aircraft via ACARS.

*The captain reported that this automated process took only a few seconds to complete.*

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2158:40 Non-pertinent background conversation commenced between the ground engineers and the flight crew, and continued while the first officer completed the take-off performance calculations (see below) until 2159:18.

*That conversation was primarily between the engineer and the augmenting captain, but included some comments from the operating flight crew. At that time, the cockpit was not required to be free of non-pertinent conversation, as this phase of the operation was not subject to the sterile cockpit policy.<sup>85</sup>*

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<sup>84</sup> An automated service for requesting a departure clearance from ATC.

<sup>85</sup> The 'sterile cockpit' policy was described in the standard communications section of the operator's FOM, Normal Operations. The policy included the requirement that during critical phases of flight '... intra-Flight Deck communications shall be restricted to essential operational issues only'. Critical phases of flight were defined in the FOM to include '... all ground operations involving taxi'.

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2158:44 to 2159:10 The first officer completed the take-off performance calculations using the EFB and transcribed the results onto his copy of the flight plan (a copy of the first page of the first officer's flight plan is provided in Appendix H).

*The first officer recalled thinking at the time that the flexible temperature value calculated by the EFB 'looked high'. He also reported that he intended to check the accuracy of that figure but became distracted by other tasks and believed that subsequent checks would detect whether the figure was inaccurate.*

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2159:18 The ground engineers and the flight crew completed their conversation and the ground engineers left the cockpit.

*There were some indistinct conversations recorded on the CVR after the ground engineers had left the cockpit that suggested they remained in the galley area outside the cockpit for a short time.*

---

2159:16 The PDC was printed on the cockpit printer.

---

2159:18 to 2200:24 The captain and the first officer discussed the PDC and the first officer programmed the SID into the aircraft FMGS.

*As previously suggested by the captain, the flight was cleared via the Bison Three SID. That SID included a discontinuity that required the crew to maintain a heading until cleared by ATC to the next waypoint in the flight plan. Each crew member indicated that they understood the SID but, at the time, the discontinuity resulted in some discussion between the captain and the first officer. This discussion initiated some non-pertinent conversation amongst the crew, including the augmenting captain.*

---

2200:25 The first officer handed the EFB to the captain and then prepared to read back the PDC to ATC.

*The first officer reported that the information required to be read back to Melbourne ATC was different to other airports that had the PDC facility. As a result, he referred to guidance material before commencing the radio call.*

---

2200:31 to 2201:00 The captain checked the EFB input data. When he commenced this check he read aloud the runway details then continued the remainder of the check silently.

*The captain reported that, while completing this check, he became distracted by other tasks and activities in the cockpit. This diverted his attention away from checking the EFB for a short period.*

---

2200:37 A non-pertinent comment was made by another person in the cockpit, to which both operating flight crew members responded.

*The comment was made at about the time the captain was checking the figures entered into the EFB.*

---

---

2201:00 to 2201:21 The captain entered the results of the take-off performance calculations from the EFB into the PERF TO page of the FMGS.

*The information entered into the FMGS included the runway, flap setting, FLEX temperature, engine out acceleration altitude, and the take-off reference speeds ( $V_1$ ,  $V_R$  and  $V_2$ ).*

---

2201:10 to 2201:48 The first officer read back the PDC to ATC.

---

2201:48 to 2201:54 The captain confirmed the PDC details with the first officer.

*This was indicated by the captain stating that he 'copied' a set of figures that corresponded to the SID, altitude limit and transponder code provided by ATC.*

---

2201:54 to 2202:07 The captain and the first officer carried out the data entry confirmation procedure.

*The purpose of the data entry confirmation procedure was to check that the data had been correctly entered into the FMGS from the EFB. The captain read aloud the information entered into the PERF TO page and the first officer crosschecked the information with the values previously transcribed onto his copy of the flight plan.*

---

2202:07 The captain read aloud the green dot speed of 225 kts and the first officer responded with 'checked'.

*The procedure required the green dot speed, from either the EFB or the quick reference handbook (QRH), and the RESULT weight<sup>86</sup> to be recorded by the captain on his copy of the flight plan; however, this was not on the copy obtained by the ATSB. The captain reported that to keep all the important information together, he would normally transcribe those values onto a separate piece of paper rather than the flight plan. There was no requirement for the green dot speed to be read aloud during this procedure.*

*Unlike the other performance parameters, there was no designated location on the flight plan to record the green dot speed.*

*The first officer reported that the majority of captains read the green dot speed aloud at this point, despite it not being a procedural requirement. He did not recall checking the green dot speed against any value when the captain called it out, and that his response may have been an unconscious automatic response to a value being read out by the captain.*

---

2202:19 The captain handed the EFB back to the first officer and asked if he was ready to check the loadsheet. The first officer then stowed the EFB.

---

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<sup>86</sup> The weight that corresponded to the resulting take-off performance figures in the EFB. Normally the same as the takeoff weight entered into the EFB, unless there was a limitation on the aircraft's performance.

---

2202:25 to 2203:26 The captain and the first officer carried out the loadsheet confirmation procedure. During that procedure, the CVR recorded the first officer reading out a take-off weight of 361.9 [tonnes].

*This take-off weight value was read by the first officer from the INIT B page of the FMGS and confirmed by the captain.*

The CVR then recorded the first officer reading the FLEX limiting take-off weight of 326.9 [tonnes] and then immediately changing this to 362.9 [tonnes]

*This FLEX limiting take-off weight was read from the first officer's copy of the flight plan.*

Towards the end of the procedure, the CVR recorded the first officer reading the green dot speed of 265 [kts]. The captain hesitated and then responded with 'yes' rather than the standard 'checked'.

*The captain was required to compare the green dot speed that was read out by the first officer from the FMGS with the figure previously recorded on his copy of the flight plan.*

---

2203:31 to 2203:55 The first officer completed the loadsheet check, *which was done silently.*

---

2203:58 The first officer announced that the loadsheet was 'checked'.

---

The leading '3' in the flexible take-off weight value (FLTOW) that was transcribed on the flight plan was not consistent with the other '3' numerals that were also transcribed by the first officer on the flight plan. This number appeared to have been changed from a '2' to a '3' (Figure 31). The effect of that alteration was to change the recorded flexible take-off weight value from 262.9 to 362.9 tonnes.

**Figure 31: Change to flexible take-off weight on the flight plan**

RWY	GWCG	FLEX	FLTOW	V1	VR	V2	ACC
16...	126.9	74	262.9	143	145	154	150
16	....	44	362.9	152	163	173	180

Tail added to 2 to change it to a 3

Initially, the first officer reported that he believed he had changed the FLTOW value, but could not recall when it was changed. Later, the first officer listened to a replay of the CVR recording at the ATSB audio laboratory. After hearing the verbal slip that was made when reading the flexible take-off weight during the loadsheet confirmation procedure, discussed above, the first officer recalled that was the time when he altered the '2' to a '3'. He also reported that, at the time he made the alteration, he believed that he had transcribed the value incorrectly from the EFB onto the flight plan.

At about the time the loadsheet confirmation procedure was completed, the augmenting first officer entered the cockpit. At that point, the preparation was ahead of schedule.

The augmenting captain reported that, although not required by the operator's procedures when in the augmenting captain role, he had a personal habit of checking the take-off performance calculations on the EFB. He did that by either reviewing those entered by the first officer, or by obtaining the second EFB and completing the calculations himself. He reported that he did not have the opportunity to do this on the accident flight due to the first officer using the primary EFB and the number of people in the cockpit during the pre-departure preparation blocking access to the second EFB.

At 2218, following the completion of passenger loading and closure of the doors, the aircraft was pushed back from the terminal ahead of schedule. At 2218:36, the engine start procedure was commenced and all four engines were started. After obtaining taxi clearance from ATC, the crew taxied the aircraft to the northern end of runway 16.

## 5.2 Takeoff

The following is a chronology of the events during the takeoff and initial climb. The aircraft's location and airspeed along the runway during this sequence of events is presented in Figure 32.

2230:09 to 2230:23	The first officer taxied the aircraft onto the runway and lined up on the centreline.
2230:42	ATC informed the crew of the current wind conditions and cleared the aircraft for takeoff.
2230:47	The engine thrust levers were advanced.
2230:51	The take-off roll began. CAS: 0 kts. <sup>87</sup> Distance to runway end: 3,536 m
2230:55	The thrust levers were moved to the FLX/MCT. <sup>88</sup> position.
2231:30	Captain announced 'one hundred knots' CAS: 98 kts Distance to runway end: 2,526 m
2231:31	Aircraft attained an airspeed of 100 kts CAS: 100 kts Distance to runway end: 2,474 m

<sup>87</sup> Computed airspeed. The airspeed computed by the aircraft's air data system and displayed to the flight crew on the primary flight display.

<sup>88</sup> FLX/MCT commands maximum continuous or flexible thrust, from the engines for takeoff.

---

2231:52 Automated announcement of  $V_1$  (the decision speed)  
CAS: 144 kts Distance to runway end: 1,118 m



---

2231:53 The captain called 'rotate'  
CAS: 146 kts Distance to runway end: 1,043 m

---

2231:54 The first officer applied back pressure on his sidestick controller to raise the nose of the aircraft.

*The aircraft did not immediately respond with a nose-up pitch and, when it did, the response was slow.*

CAS: 147 kts Distance to runway end: 964 m

---

2231:56 The captain again called 'rotate'. The first officer responded with 'rotating'.  
*The first officer applied further back pressure on the sidestick controller increasing the nose-up pitch command.*

CAS: 151 kts Distance to runway end: 805 m

---

2231:57 The nose wheel lifted off the ground.  
CAS: 152 kts Distance to runway end: 727 m

---

2231:59 The pitch rate stabilised at about  $3^\circ/\text{sec}$ .  
CAS: 154 kts Distance to runway end: 564 m

---

---

2232:03 The tail made first contact with the runway surface.  
CAS: 156 kts Distance to runway end: 265 m



---

2232:03 The captain called 'TOGA'.  
CAS: 156 kts Distance to runway end: 229 m  
*The captain reported that the decision to apply TO/GA thrust was based on the realisation that 'something was not right' with the aircraft's performance and his recollection of the reports on a previous take-off event involving another of the operator's A340-313 aircraft.<sup>89</sup>*

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2232:04.5 The captain advanced the thrust levers to the TO/GA position.  
CAS: 157 kts Distance to runway end: 57 m

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2232:05 The aircraft passed the end of the runway, still in contact with the ground.  
CAS: 157 kts  
*The FDR stopped recording.*

---

2232:06 The weight came off the main wheels as the aircraft crossed the end of stopway.  
CAS: 158 kts

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<sup>89</sup> South African Civil Aviation Authority, (2004). *Serious Incident Report CA18/3/2/0330, into the Airbus A340-313 incident at Johannesburg International Aerodrome, South Africa, on 9 April 2004.*

---

2232:07 The tail lifted off from the ground.  
CAS: 161 kts Radio altitude: -1 ft<sup>90</sup>



---

2232:08 The rear of the aircraft's fuselage struck the localiser near-field monitor antenna and a runway 34 lead-in strobe light.  
CAS: 164 kts Radio altitude: 1 ft

---

2232:09 The rear inboard tyre of the left main landing gear struck the localiser antenna as the aircraft achieved a positive rate of climb.  
CAS: 166 kts Radio altitude: 19 ft  
*The damage to the localiser antennas disabled its function and resulted in the instrument landing system becoming unserviceable.*

---

2232:22 The crew were alerted to the tailstrike by an ECAM message.  
CAS: 180 kts Radio altitude: 306 ft

---

2232:34 ATC contacted the crew seeking confirmation that operations were normal after observing multiple tail strikes during the take-off roll. ATC then asked the crew to contact the departures controller and advise of their intentions.  
CAS: 184 kts Radio altitude: 664 ft

---

2232:46 The landing gear was retracted.  
CAS: 181 kts Radio altitude: 1,050 ft

---

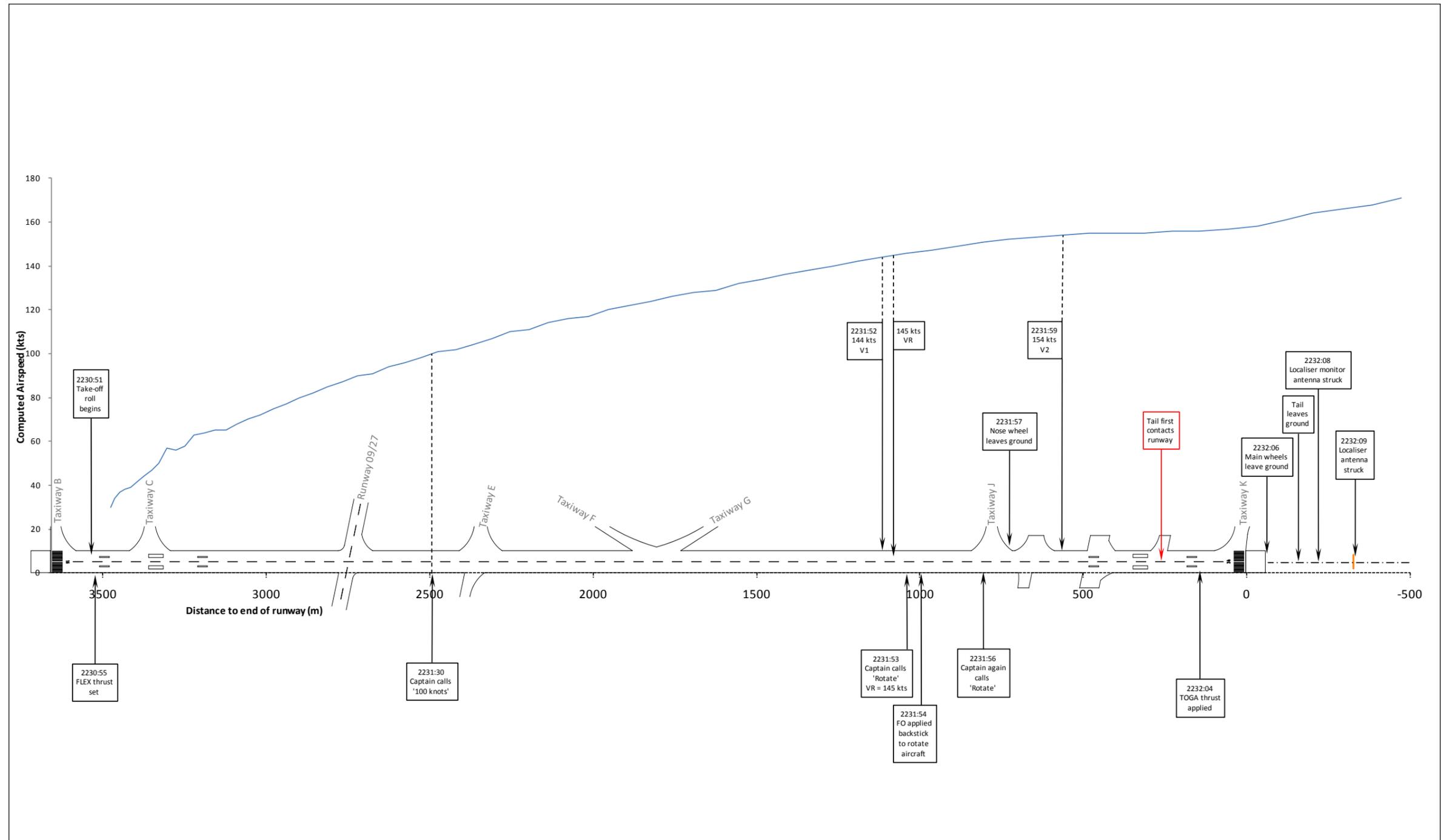
2233:13 The captain made the decision to return to Melbourne and informed the other flight crew.  
CAS: 189 kts Radio altitude: 1,705 ft

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<sup>90</sup> Height above the ground. The data is taken from the aircraft's flight recorders and was calibrated to indicate the height of the main wheels above the ground. A negative value indicates that the sensors are below their normal height when the aircraft is level. In this case, when the nose pitched up, the tail moved down and the sensors (located behind the main landing gear) were moved closer to the ground.

Figure 32: Take-off events





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## **6 ANALYSIS**

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### **6.1 Introduction**

The 20 March 2009 tailstrike and runway overrun involving the Airbus A340-541 aircraft, registered as A6-ERG, was the result of the inadvertent use by the flight crew of an erroneous data figure of 262.9 tonnes that was input during the take-off performance calculations. That input error produced erroneous take-off speeds and engine thrust settings that were used for the takeoff.

This analysis begins with an examination of the occurrence events, before discussing the individual actions and local conditions that affected the performance of the flight crew. The risk controls to prevent such an occurrence are then discussed. Several other topics of interest, including the use of the electronic flight bag (EFB), the failure of the flight data recorder rack, cabin crew communication and fatigue, are also considered.

### **6.2 Occurrence events**

The investigation identified two occurrence events that contributed to the development of the accident. Those events included the over rotation, leading to a tailstrike, and a long take-off roll, leading to a runway overrun. The following discussion examines the factors in the over rotation and long take-off roll.

#### **6.2.1 Over rotation and subsequent tailstrike**

The damage in the rear lower fuselage and marks on the runway indicated that the aircraft sustained a tailstrike during takeoff. The smooth, positive backstick command by the first officer to raise the nose resulted in a rotation rate of about 3° per second, which was within the normal range. Therefore, it was unlikely that the first officer's rotation technique contributed to the tailstrike.

The use of take-off reference speeds that were too low for the aircraft's actual weight or flap configuration of 1+F, meant that the wings did not produce sufficient lift to raise the aircraft off the ground before the geometric pitch limit was reached, and the tail contacted the runway. The only relevant cockpit indication provided to the flight crew was the tailstrike pitch limit indicator on the primary flight display (PFD). It is unlikely that the flight crew had time to recognise that the aircraft had not lifted off at the expected pitch angle of about 8° before the aircraft reached the geometric limit of 9.5°. It was therefore unlikely that the flight crew could have identified the over rotation using the PFD indicator, given that the rotation rate of 3° per second would have given them about half a second to perceive the information and react.

The rotation manoeuvre was initiated at a speed lower than necessary for the aircraft's weight and this meant that the wing was unable to provide sufficient lift for the aircraft to lift off as expected at the normal pitch attitude. The investigation concluded that the over rotation and tailstrike were due to the incorrect rotation speed and flap configuration for the actual weight of the aircraft.

## **6.2.2 Long take-off roll and subsequent runway overrun**

The additional distance travelled by the aircraft to reach  $V_1$ ,  $V_R$  and  $V_{LOF}$  was due to the acceleration being lower than required. The operation of the engines was normal and the thrust being produced was appropriate for the calculated FLEX temperature. Given there was no indication of a retarding force, such as a locked brake or excess aerodynamic drag, the low acceleration was the result of a lower thrust setting than that required for the actual aircraft weight.

The crew's lack of awareness of the low acceleration until towards the end of the take-off roll meant that, by the time the captain selected Take-off/Go-around (TO/GA) thrust, a runway overrun was inevitable. The increased thrust from that selection increased the aircraft's acceleration and resulted in the aircraft becoming airborne and climbing away from the ground much earlier than it would have otherwise. The captain's selection of TO/GA therefore reduced the likely significant adverse consequences of the runway overrun.

## **6.3 Individual actions and local conditions**

There were a number of actions taken by the flight crew during the pre-departure phase that contributed to the accident, two of which directly influenced the occurrence events. Those were the:

- use of erroneous performance data for the takeoff
- lack of recognition of the degraded take-off performance until very late in the take-off run.

### **6.3.1 Use of erroneous performance data**

A direct comparison of the erroneous take-off reference speeds that were used in the takeoff with those derived by the investigation for the aircraft's actual weight was not possible due to the differences in aircraft configuration associated with the different take-off weights. However, as previously discussed, the reduced take-off reference speeds and incorrect take-off configuration adversely impacted on the lift available for the takeoff. Compounding that reduction in lift, the significantly higher FLEX temperature resulted in a much lower engine thrust setting than necessary for the takeoff.

Although the recorded information showed that the erroneous figures were entered into the Flight Management and Guidance System (FMGS) during the pre-departure phase, there was no indication that the flight crew were aware that the take-off performance figures were incorrect until after the tailstrike.

### **6.3.2 Incorrect take-off weight entered into the EFB**

The introduction into service of the EFB resulted in the take-off performance calculation changing from an interactive process of referencing charts and tables to a simple data entry and retrieval exercise. All of the calculations were performed by the computer and the results presented to the crew. The relatively simple actions of data entry and retrieval probably resulted in the process becoming quite automatic, with little conscious oversight by the crew members. Because of the automatic nature of this process, the crew member entering the data into the EFB would be

unlikely to detect any errors made unless the software provided an error message or if there was a significant and unusual result.

There are a range of explanations for the entry of the erroneous take-off weight of 262.9 tonnes into the EFB by the first officer, including confusion with the zero fuel weight figure of 226.6 tonnes or a mental slip while adding the last-minute changes to the take-off weight in a busy, distracting environment. It was, however, considered most likely that the first officer made a typing slip, where the '2' key was accidentally pressed instead of the adjacent '3' key, and that he did not detect the error.

### **6.3.3 Erroneous take-off weight undetected**

Three factors were identified as contributing to the non-detection of the take-off weight data entry error. These were the:

- non-adherence to standard operating procedures
- first officer reading out the correct weight during the loadsheet confirmation procedure
- first officer amending the take-off weight figure that was recorded on the flight plan to the correct weight, without investigating the discrepancy.

Research into human error has shown that we are capable of making errors across a variety of tasks, and safety investigations aim to identify how such errors remain undetected by a system's risk controls and/or defences. Errors generally do not occur in isolation and there is usually a series of events/actions that combine within a particular context to produce an error.

In this accident, a series of actions and omissions reduced the effectiveness of the procedural checks and resulted in the crew not detecting the difference between the actual take-off weight and that entered into the EFB.

The first officer's reported focus of attention to the right of the take-off weight figure, combined with the routine nature of transcribing the value from the EFB onto the flight plan, meant that it was probable he saw the '2' in the place of the '3' but did not detect that it was erroneous. He also reported that while he thought the FLEX temperature appeared to be high, he became distracted and did not investigate this further.

The fact that the values read out by the crew during the pre-departure checks matched the values on the aircraft systems and loadsheet, reduced the chance the crew would detect the error with the EFB entry weight.

The operator's pre-departure procedures included five checks that were intended to detect take-off weight data entry errors in the performance calculation. Those checks were included in the:

- Take-off performance error check
- Take-off data check
- Loadsheet confirmation procedure.

### ***Take-off performance error check***

The take-off performance error check included a check of the data input into the EFB that was performed silently by the captain, and a verbal check by the captain and first officer of the EFB 'result' take-off weight against the FMGS INIT B page take-off weight (Figure 33).

As the captain's EFB input data check did not require verbal crosschecking, the investigation could not determine conclusively from the recorded information whether or not the captain completed that check. Whereas the cockpit voice recorder (CVR) recorded the captain commencing the check after he received the EFB from the first officer, the required verbal comparison between the captain and first officer of the take-off weight in the FMGS INIT B page with the EFB 'result' weight did not occur.

That omission might have been explained by the large amount of activity in the cockpit at that time. Research into aural distraction has found that such distraction significantly degrades a person's ability to apply their full attention to a task, and any distraction of the captain's attention away from the performance error check increased the risk that it would be missed.

The discussion of an apparently confusing aspect of the planned standard instrument departure (SID) procedure would have added to the workload as the captain checked the EFB and the first officer conducted the pre-departure clearance (PDC) readback. The discussion of the SID may have drawn the captain's attention to the first officer's PDC readback, distracting him from checking the EFB input data. That was consistent with the captain's statement that he 'copied' aspects of the PDC from ATC, indicating that his attention was on that communication.

The above distractions may have reduced the captain's available attentional resources for the take-off performance error check. If the distractions did interrupt that check, the captain may have inadvertently resumed it after the take-off weight verification. He may also have not completed the check after becoming distracted, instead commencing the next action of entering the data into the FMGS, not realising that the take-off performance error check was incomplete.

In turn, the first officer's attention on the PDC readback may have distracted him from participating in the take-off performance error check. That would explain the recorded gap in the first officer's involvement until he began assisting the captain with the data entry confirmation.

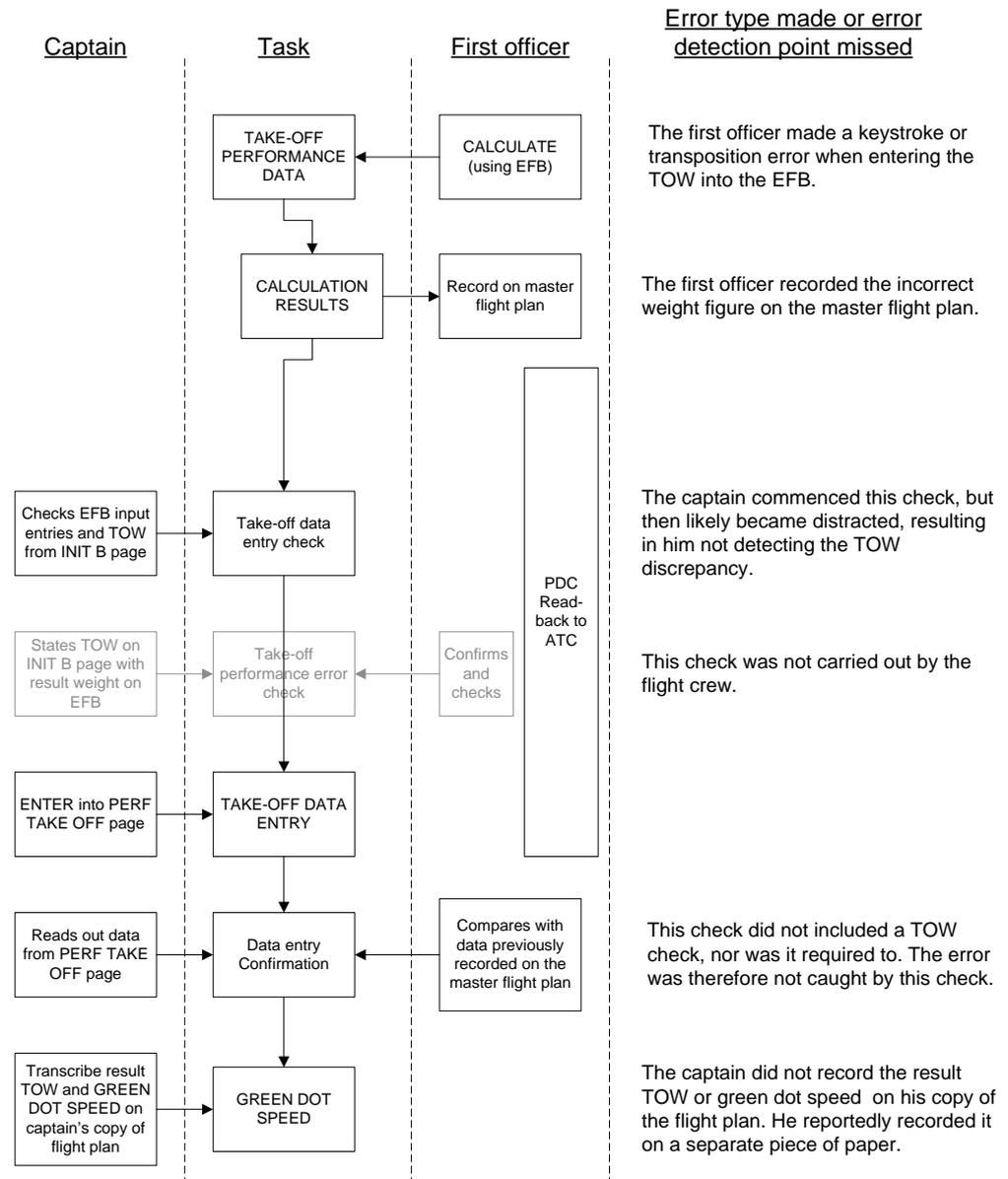
At the completion of the data entry confirmation, the captain's action to not transcribe the take-off weight and green dot speed onto his copy of the flight plan and his reading out of the green dot speed in the busy cockpit, negated one of the operator's defences that might normally have detected the error. The first officer's likely automated response of 'checked' to the captain's verbalisation of the green dot speed from the EFB was consistent with him not comparing it to the value displayed on the FMGS. The effect of that response may have been to influence the captain to incorrectly accept the different green dot speed during the loadsheet confirmation procedure as this speed had previously been 'verified' by the first officer's response.

The captain's experience of the reliability of the EFB-derived take-off performance figures may have established an expectation that the results would most likely be correct. In combination with the in-cockpit distractions, that may have reduced the

captain's level of attention to the checking process, thereby reducing its effectiveness.

Although not required by the operator's procedures, had the augmenting captain the opportunity to perform his own check of the take-off performance calculations, he may have detected the take-off weight entry error.

**Figure 33: Take-off performance error check**



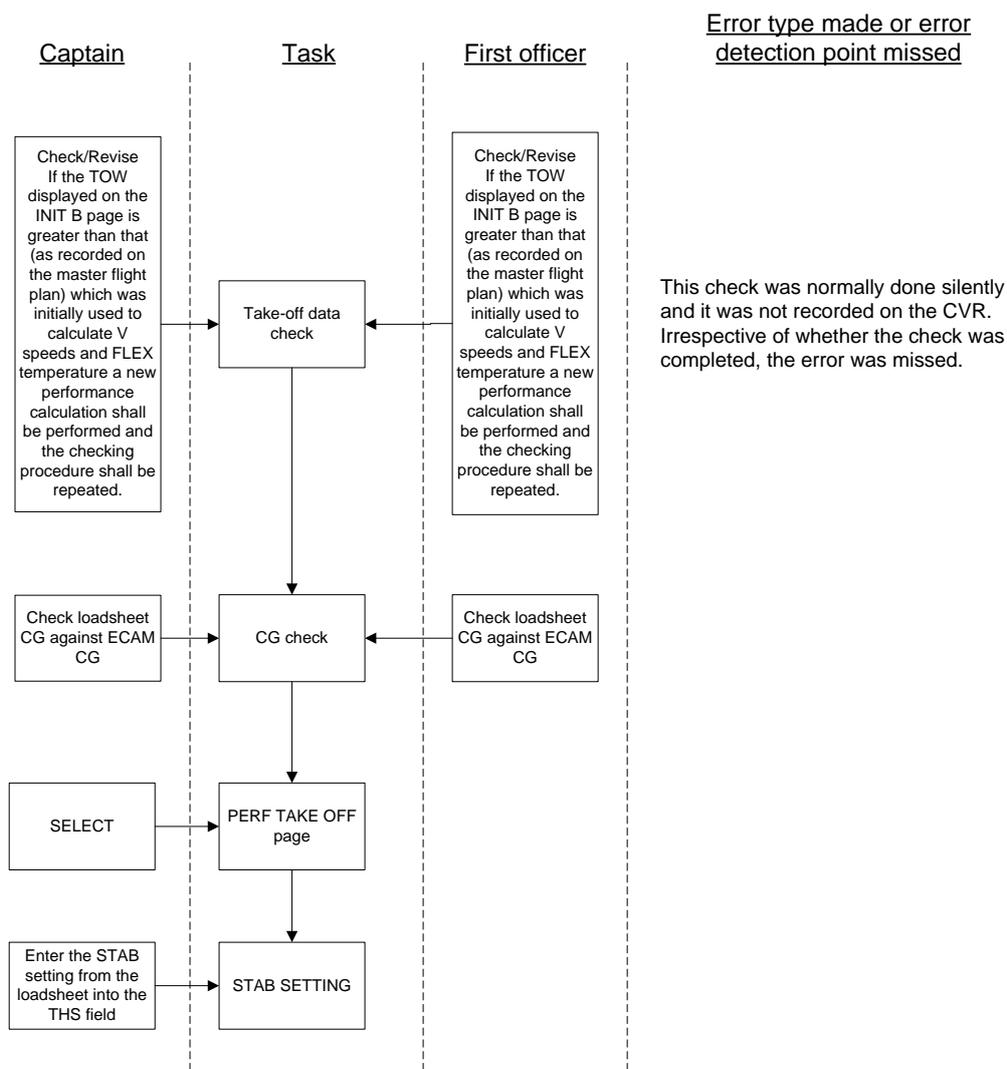
**Take-off data check**

The take-off data check was to be carried out following receipt of the final load sheet, and included a requirement for both crew members to silently verify that the take-off weight displayed on the INIT B page was greater than the FLEX-limiting take-off weight previously recorded by the first officer on the master copy of the flight plan (Figure 34).

The take-off data check could be interpreted in two different ways as a result of its wording and sequencing. The use of the term ‘CHECK/REVISE IF REQ'D’ could lead flight crew to think that the check was only required if there was a change to the zero fuel weight (ZFW) on the FMGS INIT B page, as identified by the captain’s review of the loadsheet. Given that the procedure required the take-off performance calculation to be carried out following the receipt of the revised ZFW, it is probable that the take-off weight does not often change from that used in the take-off performance calculation. This would act to reduce the significance of the check, and make it appear to be a superfluous repeat of the take-off performance error check carried out shortly before. On the accident flight the take-off performance calculation was made after the loadsheet had been received and printed.

The lack of a requirement to verbally verify the two take-off weights prevented the investigation from confirming whether this check was carried out by the crew. However, if it was carried out, it was ineffective and neither the captain nor the first officer detected the erroneous take-off weight.

**Figure 34: Take-off data check**



### ***Loadsheets confirmation procedure***

The loadsheet confirmation procedure provided the final two procedural defences to detect the error in the take-off weight (Figure 35). The first was when the first officer read out the take-off weight from the FMGS INIT B page and then the 'result' take-off weight from the master flight plan.

The first officer read the weight from the INIT B page correctly as 361.9 tonnes, but when he read the value from the master flight plan he read 326.9 tonnes. He was then heard to immediately change this to 362.9 tonnes, even though the value recorded on the master flight plan was 262.9.

It is likely that, having just read the weight as 361.9 tonnes from the INIT B page, and knowing that this was correct, the first officer automatically started to say the 'three' (of 362.9) when reading the 'result' weight from the master flight plan because this was, logically, the next value. However, on seeing 262.9 he verbalised the value as 326.9, before, upon realising the transposition of the '2' and '6', 'correcting' it to 362.9. This was consistent with his understanding of the actual take-off weight. The first officer reported that he changed the number on the flight plan from a '2' to a '3' at this point during the procedure because he thought that he had made a simple transcription error when recording the values from the EFB on the flight plan. Since he believed he had made a simple transcription error, the first officer did not investigate the discrepancy, thereby removing the opportunity to detect the original data entry error in the EFB.

There was no specific requirement for the captain to refer to the 'result' weight on his copy of the flight plan. It is reasonable to expect that the captain would only have been comparing the values verbalised by the first officer, and those values satisfied the requirements of the check. That was, the INIT B take-off weight did not exceed the verbalised 'result' weight.

The final opportunity for the flight crew to detect the data entry error was the gross error check that compared the green dot speed values obtained from the EFB and FMGS. That check required the captain to compare the green dot speed read out by the first officer from the FMGS PERF TAKEOFF page with that calculated by the EFB and recorded by the captain on his copy of the flight plan. A difference of 3 kts or more indicated a weight input discrepancy and had to be resolved by the crew.

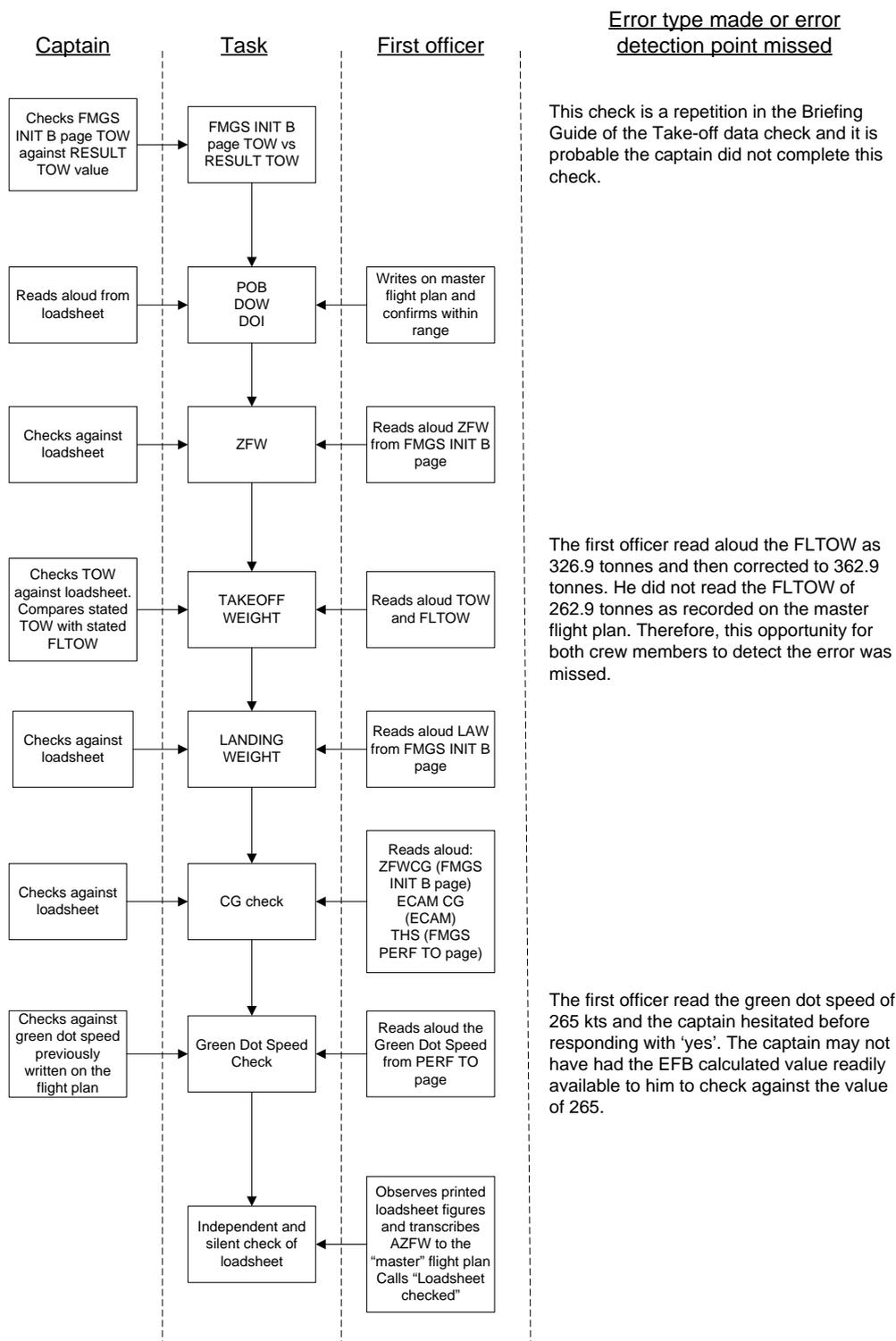
The captain's hesitation and then non-standard response of 'yes' when the first officer read out the value of 265 kts from the FMGS INIT B page suggested that the captain was thinking about the value, rather than directly comparing it to a figure that was written down to confirm its acceptability. At that time, the captain had been crosschecking the first officer's verbalised figures against the load sheet, and therefore may not have had his transcribed EFB green dot speed readily available for comparison. Instead, the captain may have relied on his recollection of the value calculated by the EFB.

Given that both green dot speeds had the same first and last number (that is '2-other value-5'), and the emphasis of the criteria was that the speeds had to be within 2 kts of each other, it is possible that the captain's attention was drawn to the last digit, as he expected any difference to occur there. Because both numbers ended in a 5, it may have appeared to the captain that the 2 kts criterion was satisfied.

The flight crew's reported trust in the performance calculation adversely affected their critical analysis of the results obtained. This trust in the standard operating

procedures as a defence was likely reinforced by their previous experience of those procedures routinely detecting such errors.

**Figure 35: Loadsheet confirmation procedure**



In summary, the crew's non-detection of the erroneous take-off weight entry in the EFB was multifaceted, and reduced the effectiveness of the procedural checks that could, individually, have detected the error. It is possible for errors to pass

undetected through various checks, which is why most procedures incorporate multiple independent checks to verify critical information.

Such errors are not confined to any particular aircraft type, operator or type of operation. It is likely that, given that the current risk controls across operators are procedural in nature, these errors will continue to occur in normal operations throughout the world.

#### **6.3.4 Degraded take-off performance not detected**

All the calls made, and actions taken by the flight crew were typical of a normal takeoff until the point where the captain called a second time for the first officer to 'rotate'. There were no indications from the communications or actions in the cockpit that any of the flight crew were aware of, or able to detect, that the aircraft's performance was insufficient for a safe takeoff. It was not until the aircraft approached the end of the runway, without lifting-off as expected, that the captain realised there was a problem and applied TO/GA thrust.

Flight crew monitoring of take-off performance is based on a set of reference speeds during the take-off roll and does not include the monitoring of the aircraft's acceleration. Therefore, if the take-off reference speeds are incorrect, or the acceleration insufficient, flight crew have no reliable indication of any problem. Accordingly, it is difficult for crew to identify that take-off performance is degraded. Two items of information are required for flight crew to determine degraded take-off performance:

- a measure of the aircraft's actual acceleration, in real time
- a reference, or expected, level of aircraft acceleration.

There was no indication of the actual aircraft acceleration available to the flight crew on the night of the accident. The only sources of information on the aircraft's take-off performance were the airspeed indication on the primary flight display, information from the engine instruments, and the pilots' perception of the acceleration. As previously discussed, airspeed alone provides no indication of acceleration and the engine instruments provide an indication of engine thrust and other parameters. Flight crew have to derive engine-related problems from those parameters. A human's ability to determine acceleration is neither an accurate nor reliable means to assess take-off performance. Furthermore, that accuracy and reliability is further degraded in darkness.

At the time of the accident, an indication of the expected acceleration was not provided to the crew, nor was it required to be. The take-off performance philosophy was based on the aircraft accelerating at a rate commensurate with the performance calculations.

Without a quantitative method for assessing the actual acceleration attained during the take-off roll, or having a 'reference' acceleration to compare with the actual acceleration, the flight crew could only judge the aircraft's acceleration in comparison with their previous experience. All four flight crew reported that they 'felt' that the aircraft's acceleration was consistent with a 'heavy' A340, specifically an A340-313K and were not alerted to the low acceleration.

All four flight crew members had encountered a large variation in take-off performance due to: the use of reduced thrust takeoffs; operating a variety of

aircraft with significant differences in take-off weight (due to differing routes and passenger/cargo loads); and differences in runway lengths and ambient conditions. The result was that there was no experience-based acceleration ‘datum’ against which the crew could measure the takeoff. That was consistent with the recorded data, which showed that there was no direct correlation between acceleration and take-off weight. For example, the take-off weight for the previous flight from Auckland to Melbourne was 8% greater than the flight from Melbourne to Auckland, but the acceleration was about 80% lower.

None of the four flight crew members raised any concerns regarding the aircraft’s acceleration during the take-off roll, demonstrating the inherent difficulty in detecting degraded take-off acceleration.

### **6.3.5 Large variations in take-off weight**

In the previous 2 months of operations, the flight crew were exposed to take-off weights that varied from about 150 to 370 tonnes. This large variation probably affected the conspicuity of the erroneous first ‘2’ in the take-off weight that was displayed in the EFB as it, in itself, was not abnormal. Both the captain and the first officer had operated the A340-541 with take-off weights in the 200 to 300 tonne range, and observing a take-off weight of 262.9 tonnes would not have been sufficiently conspicuous to alert the crew to the possibility of the data entry error.

The crew’s experiences of differing take-off weights would have been further complicated by their mixed fleet flying. Exposure to large take-off weight ranges makes it difficult for flight crew to form an expected ‘normal’ weight, and has been observed as a factor in other erroneous take-off performance incidents and accidents.

### **6.3.6 Variations in take-off performance parameters**

The large variability in take-off performance experienced by the crew over the previous 2 months, and the lack of a simple, effective correlation between the weights and parameters, meant that crews were unable to develop mental models, or ‘ballpark’ figures, to assist them in detecting whether one or more of the parameters in a given set of take-off performance figures were anomalous. This was reflected in the flight crew’s comment that the take-off performance figures had lost significance and had become ‘just numbers’.

To further complicate the situation, all four flight crew had experienced parameters in the A340-541 that were very similar to the erroneous values experienced on the night. As such, the take-off performance figures were not sufficient in themselves to alert the crew to the erroneous take-off weight used to calculate the figures.

Another complicating factor for the crew’s ability to comprehend erroneous parameters was the use of the OPT CONF (optimum configuration) option in the EFB, which selected the high-lift device configuration that gave the lowest take-off speeds. Small changes in ambient conditions could result in a change in the take-off configuration, and associated take-off speeds. That increased the difficulty for flight crews to correlate the parameters, even from an airport from which they commonly operated, such as their home port of Dubai.

The factors affecting the crew's ability to determine the 'reasonableness' of the take-off performance parameters is discussed further in section 6.4.4 of this report, titled *Reasonableness self-check*.

## **6.4 Risk controls**

### **6.4.1 Distraction management**

Research on distraction and interruptions has identified their detrimental effect on the formation and detection of errors. The research has also highlighted that the majority of errors occurred during the pre-departure phase of a flight. Thus, it is important to manage distraction during this flight phase to minimise the potential for errors to be formed and not detected until they have effect.

The calculation and checking of the take-off performance was critical to the safety of the flight, yet there was no guidance provided by the operator on the management of distraction during that process. The operator had identified other flight phases as critical to the safety of flight, such as taxi, takeoff and climb, and had a sterile cockpit rule for those phases. There was no such management practice to reduce the potential for distraction during the take-off performance calculation and checking process. Together with the operator's requirements for its flight crews to cooperate with all other personnel involved in a flight, including ground staff, this increased the risk that flight crew would be distracted by other personnel during those interactions.

The lack of clear direction on the role of, and required input from the augmenting crew during the pre-departure preparation further increased the distraction risk to the operating flight crew. That was consistent with the reports that the presence of augmenting crew in the cockpit during the pre-departure phase created a distraction for the operating crew.

By not including a component on the management of in-cockpit distractions in the operator's training program, the operator effectively left it to flight crews to develop their own distraction management practices based on their operational experiences and the environment in which they were operating. Without ongoing, formal reinforcement, such as through simulator exercises, it could be expected that the importance placed by crews on distraction management might diminish, potentially increasing their acceptance of continued interruptions from ground crew during the pre-departure phase.

The provision by the operator of briefings to flight crews on distraction management in the months prior to the accident appear to have been ineffective in this accident. Ongoing, formalised training might have alerted the captain to the distraction risk of the non-linear task completion risk represented by his check of the EFB input while the first officer was carrying out an ATC readback.

The prevalence of distraction as a contributor or influence in error development is well documented in human factors research. The challenge for operators is to develop and implement training and standard operating procedures that enable flight crew to manage distractions during safety-critical tasks, especially during the pre-departure phase.

#### **6.4.2 Standard operating procedure design/usability**

The conduct of the take-off weight comparisons within the takeoff performance error check, take-off data check, and loadsheet confirmation procedure, within a relatively short period of time, may have been perceived by flight crew as redundant. Given that on the accident flight, the take-off performance calculation was based on the final, and therefore unchanging weight figures, the risk that the three, close proximity checks might appear superfluous was heightened. That might explain to some extent why only the final loadsheet confirmation procedure was completed.

Standard operating procedures are typically designed on the basis that information flow into the cockpit is sequential and the procedures are conducted in a linear fashion based on this sequential information flow. Research has shown that the information flow into the cockpit during line operations typically does not follow the sequence upon which the procedures are based. This increases the likelihood that, following a distraction, the flight crew will re-enter a procedure at an incorrect point. The sequence of delivery of information may also lead the crew to believe that a check is no longer required.

The reported normal practice for flight crew to add 1,000 kg to the take-off weight in an A340-541 before it was entered into the EFB, to allow for last minute changes to the load, appears to be a strategy used by flight crew to avoid having to recalculate the EFB figures in the likely event the final weight figures differed to those initially used. It is probable this strategy developed from the regularity of last minute changes, and 1,000 kg covered all possible changes that did not require the issue of a new loadsheet.

#### **6.4.3 Documentation design**

Given the captain's deviation from the requirement to record the green dot speed on his copy of the flight plan, and the wide variation noted in the documentation obtained for the preceding 2-month period, it seems likely that the lack of a specific position on the flight plan for recording the green dot speed led crew members to develop their own method for recording it.

While these individual methods did not strictly comply with standard operating procedures, they did comply with the intent, which was to note the speed in order to conduct a subsequent comparison during the load sheet confirmation procedure. However, the variation by crews in recording the green dot speed, and therefore lack of a consistent and predictable information source, increased the risk that any EFB data entry errors would remain undetected.

#### **6.4.4 Reasonableness self-check**

A number of factors influenced the flight crew's ability to determine the 'reasonableness' of the take-off performance figures calculated by the EFB. One of the main factors was the variation of those parameters as experienced by the flight crew during normal operations. The normalcy of that variation in parameters increased the difficulty for flight crew to recognise inappropriate outputs from the EFB. The reasons for this variation have been discussed previously.

This problem is not unique to this accident. Previous investigations into similar data entry error and tailstrike occurrences have highlighted the inability of flight crew to

conduct a ‘rule of thumb’ or reasonableness check of speeds when moving between aircraft types. Furthermore, an unintended consequence of mixed fleet flying appears to be a reduction in a flight crew’s ability to build a model in long-term memory to facilitate recognition of ‘orders of magnitude’, or a ‘rule of thumb’, in respect of take-off performance data. Because the figures that are quite reasonable for one variant may not be reasonable for another variant, the flight crew would need to build a model for each variant that they operate.

There was no specific guidance in the regulatory or operator’s documentation to assist flight crew in forming appropriate mental models regarding the weight and corresponding take-off performance parameters for a particular flight.

## **6.5 Other safety factors**

### **6.5.1 Electronic flight bag/operational procedures ergonomics**

An ergonomic review of the EFB was carried out to determine the current and optimal flows of information into, and out of the EFB in the context of the operator’s procedures.

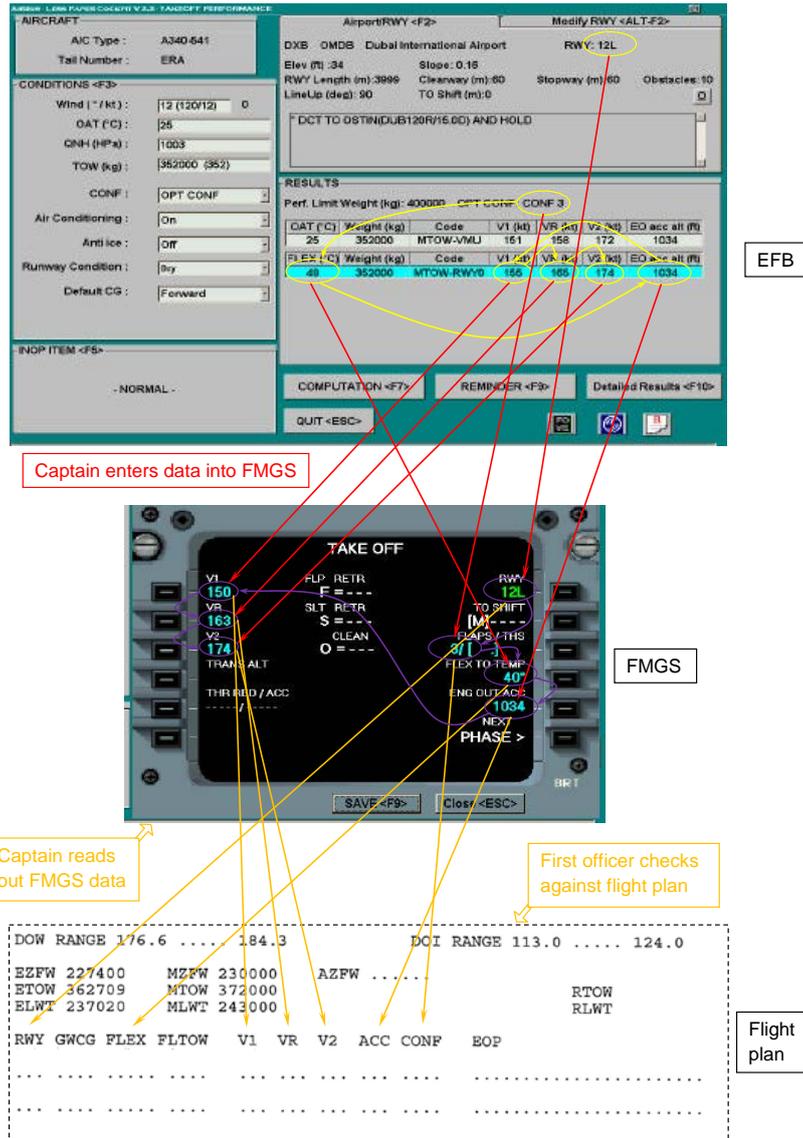
This included a review of the flow of information into the EFB, from the EFB to the flight plan, from the EFB to the FMGS, and from the FMGS to the final check against the flight plan. Figure 36 shows the link analysis for the flow of information from the EFB to the FMGS and then to the flight plan for the final check.

The analysis found the flow of information into the EFB and onto the flight plan was clear and simple. Because the EFB and flight plan mirrored each other with regard to the layout of information, the flow was easy to follow and sequential.

The analysis of the information flow from the EFB to the FMGS MCDU revealed a different situation. It was more complicated, less sequential, and required the focus of the user’s attention to move around the screen. The checking process, which required flight crew to verify information from the FMGS against the flight plan, was more difficult because the values were not printed on the flight plan in the same sequence in which they were read out from the FMGS. Although this did not occur on the accident flight, this complexity increased the risk of errors in data entry and checking.

In addition to the flow of information, a number of other issues were highlighted. The first related to the inconsistency in the weights entered into the EFB and recorded on the flight plan, which varied between tonnes and kilograms. The possibility of transposition errors would be reduced if the units were consistent.

Figure 36: Link analysis on EFB



The second issue was related to the initial entry of data into the EFB. The EFB required the user to enter the take-off weight and not the individual ZFW and fuel load figures. The previous incidents highlighted the number of times that the zero fuel weight was entered into the EFB instead of the take-off weight. If the user was required to enter the ZFW, the fuel weight and the take-off weight, the EFB could perform an independent check of the figures to reduce the likelihood of a data entry error.

The final issue related to last-minute changes. To minimise the possibility of conducting last-minute recalculations of take-off performance parameters, it was common practice for users to enter a take-off weight that included an additional weight to account for the maximum permissible last minute change. This created a potential problem because, by adding this margin the flight crew could, inadvertently, enter an incorrect take-off weight into the EFB, or be less likely to identify an error in a weight value entered into the EFB because the original value had been deliberately altered during entry.

## **6.5.2 Failure of flight data recorder rack**

The vertical forces sustained by the flight data recorder (FDR) rack from the tailstrike imparted sufficient load to the rack to permanently deform the aluminium sheet of the upper tray. That allowed the securing nuts to disconnect from the FDR hooks, leaving the unit unsecured. The equal deformation on the left and right of the upper tray indicated that both fasteners were secured at the time of the occurrence. For further information on the examination of the FDR rack failure, see Appendix A.

Because the aircraft was equipped with a direct access recorder (DAR), and similar data was able to be recovered from the DAR as would normally have been available from the FDR, the investigation was not significantly hampered by the loss of FDR data. However, because the DAR is not crash protected to the same extent as the FDR, the failure of the FDR rack and therefore unavailability of data from that recorder might, in other circumstances, have implications for the safety of future operations. In particular, such damage could preclude the determination in future investigations of the sequence of events, system settings and failures in the development of an accident or incident.

## **6.6 Other information**

### **6.6.1 Fatigue**

Consistent with the results from the operator's examination of the operating crew's fatigue, the location of both operational crew members' effectiveness towards the top of the *Fatigue Avoidance Scheduling Tool* effectiveness range indicated that they were not significantly impaired by fatigue at the time of the accident. That assessment was also supported by the crew providing data that indicated they both had probably obtained sufficient rest during their layover in Melbourne. The layover time was greater than 36 hours and the captain and first officer reported that they did not feel unusually fatigued when they commenced their duty period. Moreover, there was no sound on the CVR of any crewmember yawning, and no prolonged silence or disengagement of crew from conversations (other than when necessary for operational reasons) that might be linked with crew fatigue.

The investigation determined that it was unlikely the operating flight crews' performance was impaired by fatigue at the time of the accident.

### **6.6.2 Cabin communications**

The majority of communication between the cockpit and cabin, and within the cabin, occurred without any problem. However, the cabin crewmember located at door R2 could not reach the interphone at position R2A. This did not present a problem once the aircraft was on the ground and the crew were preparing for a possible evacuation.

This did present a problem in-flight, as the crewmember was not involved in the interphone briefings and relied on the crewmembers at L2 to provide pertinent information. Given this information could be overheard by passengers, it was a modified version of the interphone conversations. While there was no direct bearing on the safety of the flight because of this, it did mean the crewmember was not fully

briefed on the situation, including the return to Melbourne, or on any hazards such as the smoke reported in the cabin during the approach. It also meant that this cabin crewmember could not pass on pertinent information directly to other crew.

## **6.7 Summary**

There were a number of similarities between the circumstances of this accident and other erroneous take-off performance data-related occurrences. In all cases examined, it was found that the manner in which the errors occurred, and went undetected were varied and was not particular to any aircraft type, operator, or procedure. However, there were two core factors that all the occurrences had in common:

- individual actions rendered operator's procedures and controls ineffective
- degraded take-off performance remained undetected until very late in the take-off roll, if at all, as there was no specific requirement or system for monitoring an aircraft's acceleration.

A number of safety recommendations have been made by several investigation agencies regarding automated take-off performance monitoring to assist flight crews during the take-off roll.

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## 7 FINDINGS

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### 7.1 Context

From the evidence available, the following findings are made with respect to the tailstrike and runway overrun at Melbourne Airport, Victoria on 20 March 2009 that involved Airbus A340-541, registered A6-ERG and should not be read as apportioning blame or liability to any particular organisation or individual.

Although there are a number of factors identified directly relating to this accident, the accident needs to be taken in the context of the long history of similar take-off performance events identified by this investigation. Even though the events leading to this accident may be particular to this case, the previous events highlight that there are a multitude of ways to arrive at the same situation, placing the aircraft and passengers in an unsafe situation before the aircraft has even been pushed back from the terminal. The preferred safety actions will be those that address the whole situation, not just those that address the specific factors identified in this accident.

### 7.2 Contributing safety factors

- The first officer inadvertently entered the incorrect take-off weight into the electronic flight bag to calculate the take-off performance parameters for the flight.
- The captain was distracted while checking the take-off performance figures in the electronic flight bag, which resulted in him not detecting the incorrect take-off weight.
- During the pre-departure phase, the flight crew did not complete all of the tasks in the standard operating procedures, which contributed to them not detecting the error.
- When conducting the loadsheet confirmation procedure, the first officer called out 362.9 tonnes as the FLEX take-off weight, rather than the 262.9 tonnes that was recorded on the master flight plan, which removed an opportunity for the captain to detect the error.
- The first officer changed the first digit of the FLEX take-off weight on the master flight plan during the loadsheet confirmation procedure, believing it had been transcribed incorrectly, which removed an opportunity for the flight crew to detect the error.
- The lack of a designated position in the pre-flight documentation to record the green dot speed precipitated a number of informal methods of recording that value, lessening the effectiveness of the green dot check within the loadsheet confirmation procedure. [*Minor safety issue*]
- The flight crew's mixed fleet flying routinely exposed them to large variations in take-off weights and take-off performance parameters, which adversely influenced their ability to form an expectation of the 'reasonableness' of the calculated take-off performance parameters.

- The operator's training and processes in place to enable flight crew to manage distractions during the pre-departure phase did not minimise the effect of distraction during safety critical tasks. *[Significant safety issue]*
- The rotation manoeuvre was commenced at an airspeed that was too low to permit the aircraft to become airborne but sufficient to overpitch the aircraft, resulting in the tailstrike.
- The application of the calculated (high) FLEX temperature during a reduced thrust take-off led to a reduced acceleration, an extended take-off roll, and the subsequent runway overrun.
- The flight crew did not detect the reduced acceleration until approaching the end of the runway due to limitations in human perception of acceleration, which was further degraded by reduced visual cues during a night takeoff.
- The existing take-off certification standards, which were based on the attainment of the take-off reference speeds, and flight crew training that was based on the monitoring of and responding to those speeds, did not provide crews with a means to detect degraded take-off acceleration. *[Significant safety issue]*

### **7.3 Other safety factors**

- The design of the flow of information from the electronic flight bag into the aircraft systems and flight documentation was complex, increasing the potential for error.
- The available Cross Crew Qualification and Mixed Fleet Flying guidance did not address how flight crew might form an expectation, or conduct a 'reasonableness' check of the speed/weight relationship for their aircraft during takeoff. *[Significant safety issue]*
- The failure of the digital flight data recorder (DFDR) rack during the tailstrike prevented the DFDR from recording subsequent flight parameters. *[Minor safety issue]*

### **7.4 Other key findings**

- It was unlikely the operating flight crew were unduly affected by fatigue.
- The captain's selection of Take-off/Go-Around (TO/GA) thrust during the rotation manoeuvre very likely limited the adverse consequences of the runway overrun.
- The inability of the cabin crew member at door R2 to reach the interphone handset that was located at seat R2A degraded the flow of communication between cabin crew members.

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## 8 SAFETY ACTION

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The safety issues identified during this investigation are listed in the Findings and Safety Actions sections of this report. The Australian Transport Safety Bureau (ATSB) expects that all safety issues identified by the investigation should be addressed by the relevant organisation(s). In addressing those issues, the ATSB prefers to encourage relevant organisation(s) to proactively initiate safety action, rather than to issue formal safety recommendations or safety advisory notices.

All of the responsible organisations for the safety issues identified during this investigation were given a draft report and invited to provide submissions. As part of that process, each organisation was asked to communicate what safety actions, if any, they had carried out or were planning to carry out in relation to each safety issue relevant to their organisation.

*Note: 'Safety factors' are events or conditions that increase risk. If a safety factor refers to a characteristic of an organisation or a system that has the potential to affect future safety, it is called a 'safety issue'. The ATSB classifies safety issues as critical, significant or minor depending on the level of associated risk, and it encourages relevant organisations to take safety action to address these issues. Further descriptions of these terms are provided in the section titled INVESTIGATION METHODOLOGY on page xiv.*

### 8.1 Aircraft operator

During the preliminary stages of this investigation, and before the investigation had identified any safety issues, Emirates undertook and advised the ATSB of the following proactive safety action.

On 17 April 2009, Emirates informed the Australian Transport Safety Bureau (ATSB) that, based on their internal investigation into this accident, the following areas of their operation were under review:

- Human factors – including the pre-departure, runway performance calculation and cross-check procedures, to determine whether the enhancement of those procedures was feasible and desirable, with particular regard to error tolerance and human factors issues.
- Training – including the operator's initial and recurrent training in relation to mixed fleet flying and human factors.
- Procedures – including the introduction of a performance calculation and verification system that would protect against single data source entry error, by allowing at least two independent calculations.
- Hardware and software technology – including liaising with technology providers regarding the availability of systems for detecting abnormal take-off performance.

On 20 October 2009, Emirates advised the ATSB that some of the working groups established following the accident were examining all the operator's aircraft types. The working groups identified areas where safety could be enhanced and, as a result, a number of safety enhancements were implemented. These included:

- briefings for all company flight crew to raise their awareness of the safety aspects of this accident;
- provision on the flight deck of a second laptop-based electronic flight bag (where not already provided) and a change in the operating procedures to require each laptop to be used by a different flight crew member to independently calculate the take-off performance;
- liaison with the aircraft manufacturer to improve the laptop-based electronic flight bag user interface;
- inclusion of dedicated modules on distraction management in the operator's crew resource management training syllabi;
- education of support staff on flight crew distraction and adjustments to pre-departure procedures to reduce the opportunities for such distraction;
- clarification of the role of the augmenting flight crew, in relation to the operating crew and the pre-departure process;
- improvement of flight plans to include specific entry locations for all pertinent information; and
- initiation of discussions with aircraft manufacturers and technology designers to urgently provide improved systems to protect against potential errors during the pre-departure phase.

The working groups also identified a number of other areas that required further consideration and/or the involvement of aircraft and system manufacturers. They included:

- improvement of the presentation, functionality and ergonomics of the laptop-based electronic flight bag to further reduce the opportunity for data input errors;
- development of a process to increase crews' situational awareness during the pre-departure phase, to indicate reasonable values for the aircraft take-off reference speeds and thrust settings;
- improvement of its aircraft's flight management and guidance systems to reduce the possibility of data input errors, such as unreasonable take-off reference speeds;
- provision of a system for a fully-independent performance data calculation; and
- development of a system to alert flight crews to abnormal take-off performance at an early stage during their takeoff runs.

Subsequent to the advice of the above proactive safety action, the investigation identified a number of safety issues in relation to the operator's policy and procedures as outlined in the following paragraphs.

### **8.1.1 Lack of a designated position for recording the green dot speed**

#### ***Minor safety issue***

The lack of a designated position in the pre-flight documentation to record the green dot speed precipitated a number of informal methods of recording that value,

lessening the effectiveness of the green dot check within the loadsheet confirmation procedure.

### **Action by Emirates**

On 21 October 2011, Emirates advised that they had introduced a designated field for the crew to record the green dot speed on the flight plan. An example flight plan showing the location of the green dot speed in the revised plan follows.

RWY	GWCG	FLEX	FLTOW	V1	VR	V2	ACC	CONF	EOP	GDOT
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Flight Plan recording field for Green Dot Speed

## **8.1.2 Management of distractions**

### **Significant safety issue**

The operator's training and processes in place to enable flight crew to manage distractions during the pre-departure phase did not minimise the effect of distraction during safety critical tasks.

### **Action by Emirates**

On 6 December 2011, Emirates advised of the following safety action in response to this accident:

Every Emirates pilot attended a senior management briefing emphasising the highest standards of professional behaviour, part of which re-emphasised the need for distraction management.

The introduction of an Alternative Training Qualification Programme (ATQP) has been a keystone in our continuous improvement programme. In addition to aircraft handling and management skills, ATQP focuses on: Human Factors, CRM, leadership, situational awareness and decision making processes and includes increased awareness of the threats posed by distraction, plus techniques to eliminate or mitigate, them.

and that:

Distraction management is integrated into all facets of our pilot training syllabi. It is specifically covered in the CRM induction training for newly joined pilots. Distraction management is also included in simulator training. Further enhancements have been added to and incorporated into the recurrent three yearly cycle for CRM refresher training. This module was first delivered in the 2010-2011 cycle and is planned to be delivered again in 2013-2014 cycle. The following extract from the Emirates CRM Training Manual lists the distraction management topics covered in recurrent training:

- Distraction management
- Consequences of distractions
- Typical pre-conditions
- Recognition of distractions
- Management of distractions

### ***ATSB assessment of response/action***

The ATSB is satisfied that the action by Emirates adequately addresses the significant safety issue.

All operators are encouraged to review the distraction management elements of their training and checking systems and consider the relevance of the Emirates action to their own operations.

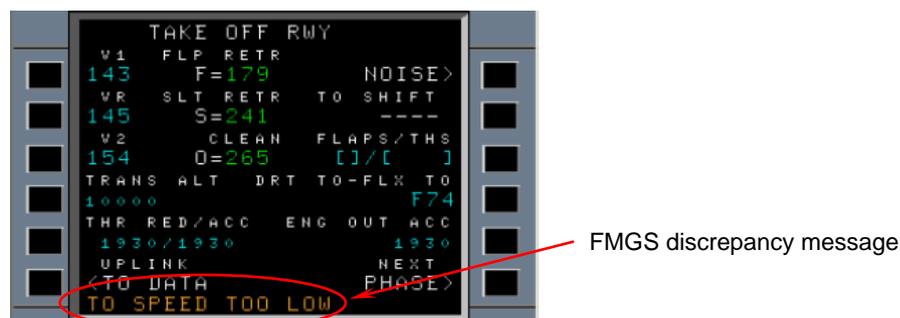
## **8.2 Aircraft manufacturer**

During the investigation, Airbus advised of the following proactive safety actions.

### **8.2.1 Take-off securing function**

In July 2009, Airbus announced in their *Safety First* magazine that they were developing a software package called the 'Take-off Securing' (TOS) function. The TOS function automatically checks the data being entered into the flight management and guidance system (FMGS) for consistency between the take-off parameters. A check is carried out on the takeoff reference speeds entered into the FMGS against take-off limitation speeds calculated within the FMGS based on the aircraft weight. If the TOS function detects a discrepancy between these speeds, it alerts the flight crew by displaying a message on the FMGS display unit.

On 28 May 2010, Airbus provided the ATSB with the results of a simulation of the TOS function for the A340 using the accident flight take-off performance parameters. The result is shown below.



On 28 October 2011, Airbus advised that they plan an additional development that will include functionality to check that the aircraft has sufficient runway length to support a safe takeoff.

### **8.2.2 Updated Less Paper Cockpit software**

On 17 November 2009, Airbus informed the ATSB that a new version of the Less Paper Cockpit (LPC) software was available which included changes to the flight crew-LPC interface.

### **8.2.3 Flight data recorder rack failure**

#### ***Minor safety issue***

The failure of the digital flight data recorder (DFDR) rack during the tailstrike prevented the DFDR from recording subsequent flight parameters.

#### ***Action by Airbus***

On 28 October 2011, Airbus advised that:

A new rack (PN S4419F01) has been certified through modification number 56124 and implemented in production line from MSN911 delivered in March 2008.

This new rack has geometrical changes and the shock-mounts have been removed. ... it has a stiffening flange which limits the deformations.

## **8.3 Australian Transport Safety Bureau**

During the preliminary stages of this investigation, and before the investigation had identified any safety issues, the ATSB commenced a safety study (AR-2009-052) on 20 August 2009 to examine the extent of take-off performance-related accidents and incidents and to identify any associated safety issues. In January 2011, the ATSB released the findings of that study in the Aviation Research and Analysis Report AR-2009-052, *Take-off performance parameter errors: A global perspective*. A copy of that report can be obtained from the ATSB website at [www.atsb.gov.au](http://www.atsb.gov.au).

## **8.4 Indication of degraded take-off acceleration**

#### ***Significant safety issue***

The existing take-off certification standards, which were based on the attainment of the take-off reference speeds, and flight crew training that was based on the monitoring of and responding to those speeds, did not provide crews with a means to detect degraded take-off acceleration.

## 8.4.1 European Aviation Safety Agency

### ***Action by the European Aviation Safety Agency***

On 28 October 2011, the European Aviation Safety Agency (EASA) advised the ATSB that:

EASA [has] already received safety recommendations on take-off performance monitoring system and, despite such system feasibility has not yet been demonstrated, is cooperating with EUROCAE<sup>[91]</sup> to set up a group of experts who will review the state of the art options, if any, which could [be] worked out to eventually develop a standard which could then be used by the industry to develop such systems. A rulemaking action could then be envisaged by EASA to require such system based on the standard.

### ***ATSB assessment of response/action***

The ATSB acknowledges the technical challenges inherent in the development of a take-off performance monitoring system. The commitment by EASA to work with industry experts to develop a standard to guide the development of such systems is appreciated. The ATSB anticipates that the action by EASA will, in collaboration with its industry and other stakeholders, maximise the likelihood of the development of a European take-off performance monitoring system standard.

## 8.4.2 United States Federal Aviation Administration

### ***Action by the United States Federal Aviation Administration***

During the investigation, the ATSB sought an understanding from the United States Federal Aviation Administration (FAA) of whether the FAA was contemplating work similar to that by EASA to develop a standard to guide the development in the US of take-off performance monitoring systems. On 6 December 2011 the FAA advised that:

...the FAA has entertained this idea before, notably, in the aftermath of the Air Florida accident here in Washington, DC, and has found the idea of these systems, with all of their inherent complexity to be more problematical than reliance on adequate airmanship. That has been the FAA position in the past. I'm sure the FAA would be happy to entertain any recommendation to re-visit the issue in the light of new information or ideas.

### ***ATSB assessment of response/action***

The ATSB believes that the development of a take-off performance monitoring system standard in the US would support the efforts of prospective US manufacturers of those systems and optimise the efficiency of any US developmental work. In addition, it could be expected that the ongoing work to harmonise FAA and EASA certification efforts would maximise any synergies

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<sup>91</sup> EUROCAE is an organisation formed to provide a European forum for resolving technical problems with electronic equipment for air transport. EUROCAE deals exclusively with aviation standardisation and related documents as required for use in the regulation of aviation equipment and systems.

between the respective regional manufacturers' developmental efforts, and the production of high quality, reliable take-off performance monitoring systems for use by the world's airlines.

The ATSB is concerned that the apparent inaction in this area by the FAA is a missed opportunity to enhance the safety of scheduled transport operations throughout the world.

#### ***Action by the ATSB***

As a result of the identified significant safety issue, coincident with the release of this investigation report, the ATSB has issued the following safety recommendation to the US FAA.

#### ***Safety recommendation AO-2009-012-SR-079***

The Australian Transport Safety Bureau recommends that the United States Federal Aviation Administration take action to address the existing take-off certification standards, which are based on the attainment of the take-off reference speeds, and flight crew training that was based on the monitoring of and responding to those speeds, and do not provide crews with a means to detect degraded take-off acceleration.

### **8.4.3 Airbus**

Airbus does not have responsibility for the development of take-off performance monitoring or other certification standards. That responsibility rests with respective national airworthiness authorities such as EASA and the FAA. Notwithstanding, Airbus has advised of the following proactive safety action in response to this safety issue.

#### ***Action by Airbus***

On 28 October 2011, Airbus advised that:

This subject is also discussed within EUROCAE association in which Airbus is involved. The item raised by the ATSB will be covered by a future function called Take-Off Monitoring (TOM).

This function will compute theoretical acceleration of the aircraft and trigger an alert (during the take-off roll) if the actual acceleration is too far from this theoretical acceleration.

For the time being, this function is under feasibility study for a certification targeted to be available in 2015 for A380 and between 2015-2020 for A320 and A330/A340 families.

#### ***ATSB assessment of response/action***

The ATSB is satisfied that the work by Airbus to develop the company's take-off monitoring system will, when that equipment is successfully installed and tested in Airbus aircraft, address this safety issue in those aircraft.

#### **8.4.4 Emirates**

##### ***Action by Emirates***

On 21 October 2011, Emirates advised that they were assisting a major avionics company to develop a take-off acceleration monitoring and alerting system.

##### ***ATSB assessment of response/action***

The ATSB recognises the inherent technical difficulties associated with the development of a take-off monitoring and alerting system, and understands that this project is in the very early stages of research into such a system. However, the ATSB believes that the equipment will, when successfully developed and installed in scheduled transport aircraft, significantly enhance the safety of operations in all aircraft with such equipment installed.

#### **8.5 Guidance on Cross Crew Qualification and Mixed Fleet Flying operations**

##### ***Significant safety issue***

The available Cross Crew Qualification and Mixed Fleet Flying guidance did not address how flight crew might form an expectation, or conduct a 'reasonableness' check of the speed/weight relationship for their aircraft during takeoff.

##### ***Background***

The problem experienced by the flight crew in determining the 'reasonableness' of the take-off performance figures that were calculated by the electronic flight bag is not unique to this accident. Previous investigations into similar data entry error and tailstrike occurrences have highlighted the inability of flight crew to conduct a 'rule of thumb' or reasonableness check of their take-off speeds.

Furthermore, an unintended consequence of mixed fleet flying appears to be a reduction in a flight crew's ability to build a model in long-term memory to facilitate recognition of 'orders of magnitude' or 'rules of thumb' in respect of take-off performance data. That is, the effect of mixed fleet flying appears to exacerbate the difficulty already being experienced by crews in discerning the appropriateness of their aircraft's performance.

Indeed, because performance figures that are quite reasonable for one variant may not be reasonable for another variant, affected flight crew would need to build a model for each aircraft variant experienced. Currently, there is no specific guidance to assist flight crew to form those mental models in respect of the weight and corresponding take-off performance parameters for a particular aircraft variant.

##### ***Action by the ATSB***

The ATSB recognises that the existing avionics technologies have as yet been unable to develop a take-off monitoring and alerting system. However, given that equipment unavailability, the ATSB remains concerned at the present lack of take-off performance monitoring guidance available to flight crews who are

involved in mixed fleet flying. In that context, consideration was given to the most effective means of promoting relevant safety action among the world's operators. Ultimately, that means of communication was determined to be via a safety advisory notice (SAN) that sought the assistance of the International Air Transport Association (IATA) and Flight Safety Foundation (FSF). The intent was that those organisations would, through their members, be best equipped to address the safety issue. Hence, the ATSB issues the following SANs to IATA and the FSF.

## **8.5.2 International Air Transport Association**

### ***ATSB safety advisory notice AO-2009-012-SAN-087***

The Australian Transport Safety Bureau requests the International Air Transport Association to encourage its members to develop guidance to assist their flight crews form appropriate mental models in respect of the weight and corresponding take-off performance parameters for a particular flight. The application by operators of mixed fleet flying increases the need for that guidance.

## **8.5.3 Flight Safety Foundation**

### ***ATSB safety advisory notice AO-2009-012-SAN-086***

The Australian Transport Safety Bureau requests that the Flight Safety Foundation consider developing guidance to assist flight crews form appropriate mental models in respect of the weight and corresponding take-off performance parameters for a particular flight. The use by operators of mixed fleet flying increases the importance of that guidance.



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## APPENDIX A : EXAMINATION OF FLIGHT DATA RECORDER RACK

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### A.1 Background

The flight data recorder (FDR) was dislodged from its rack, and was found on the floor of the rear fuselage of Airbus A340-541 A6-ERG (Figure A1). The FDR and associated rack were examined at the Australian Transport Safety Bureau laboratory.

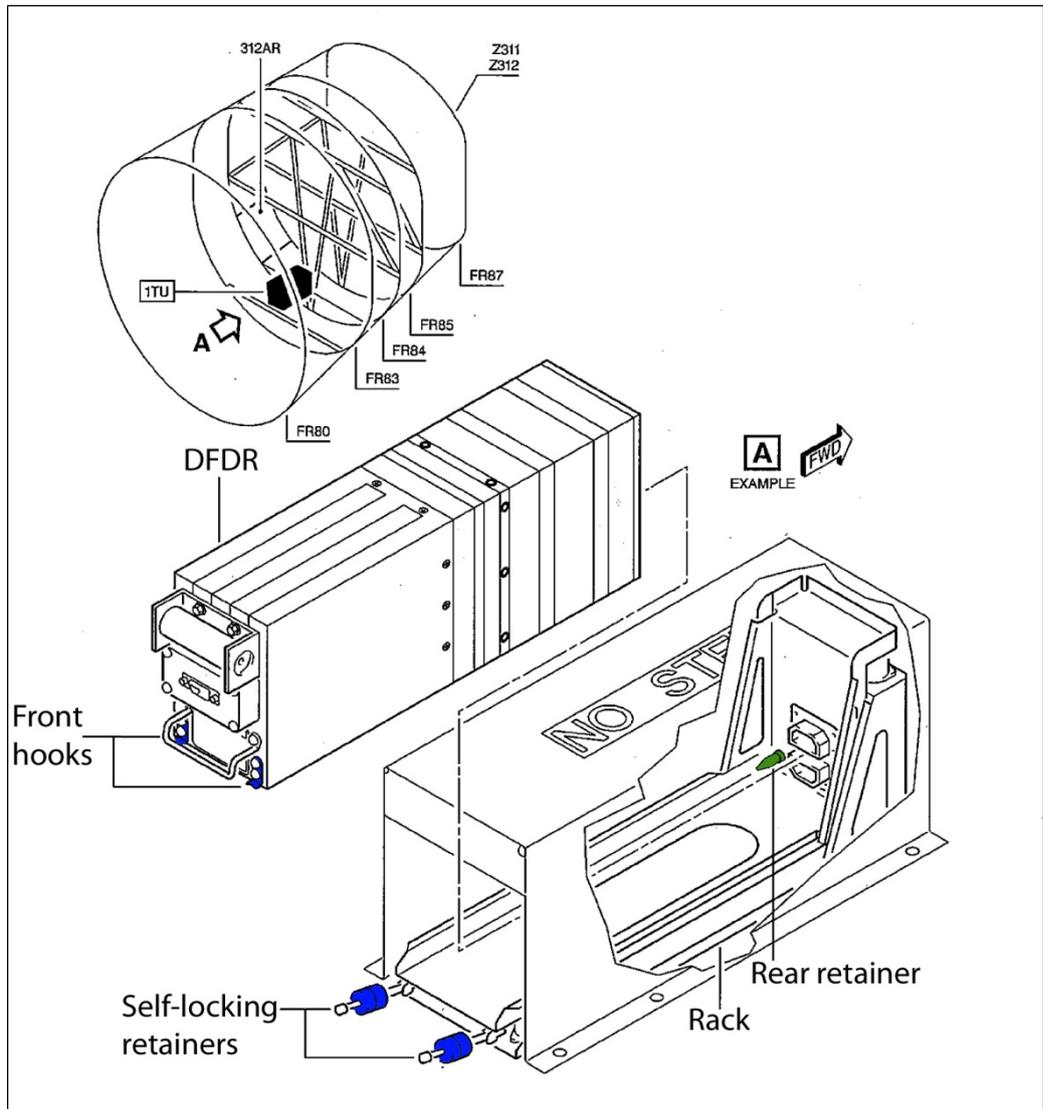
Figure A1: FDR and rack as found on-site



### A.2 Physical examination

The FDR was normally secured in the rack with two attachment hooks on the front of the unit. The fasteners used for securing the FDR are known as positive self locking retainers, and work on a spring loaded mechanism (Figure A2). The knurled outer sections of the fastener are placed over the hooks on the front of the FDR, and then tightened via the internal nut to lock it in position. The spring forces the lower section to lock onto the top segment (closest to the rack) which cannot rotate around the rod. The fastener is loosened by pulling on one side of the outer casing, to release the locked mating faces, allowing for the threaded nut to be undone.

**Figure A2: Schematic diagram showing the orientation of rack/FDR in aircraft**



***Flight data recorder***

Examination of the FDR revealed it to be in a generally good condition. Evidence of minor dents and scratches were observed at a number of locations on the outer surfaces of the recorder. These markings were consistent with the FDR’s contact with surrounding objects following its separation from the rack.

The front hooks were in good condition, with no evidence of deformation or mechanical damage. Some paint had been removed in the area adjacent to the right attachment hook.

***FDR rack***

The following identification markings were observed on the label on the rear of the FDR rack;

TRAY PN	404-050L1DPX2-1
SN	2143

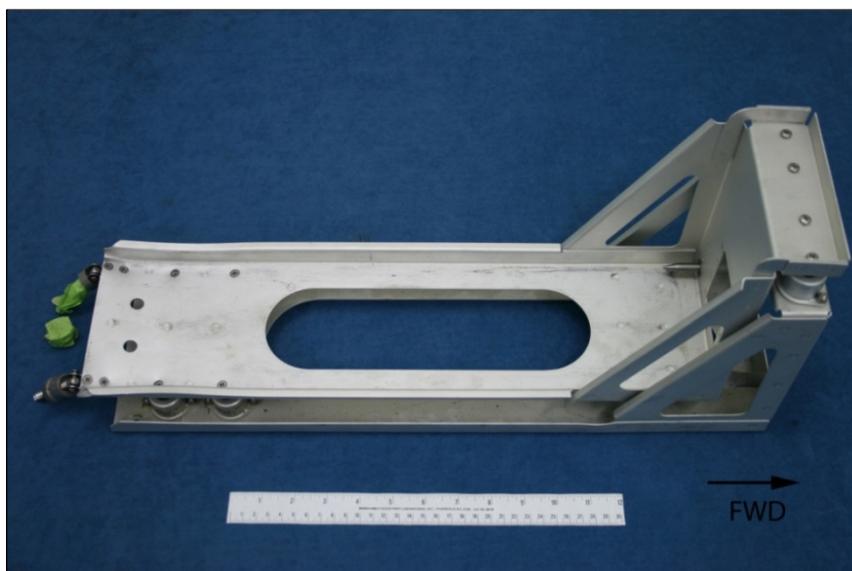
On-site photographs (Figure A3) indicated that the left fastener (as viewed from the front of the rack) was slightly less engaged than the right. On the left, a total of 18 threads were visible from the top of the threaded rod to the intersection point with the top nut, while 14 threads were visible on right.

**Figure A3: On-site photograph showing the original position of the threaded fasteners following the occurrence**



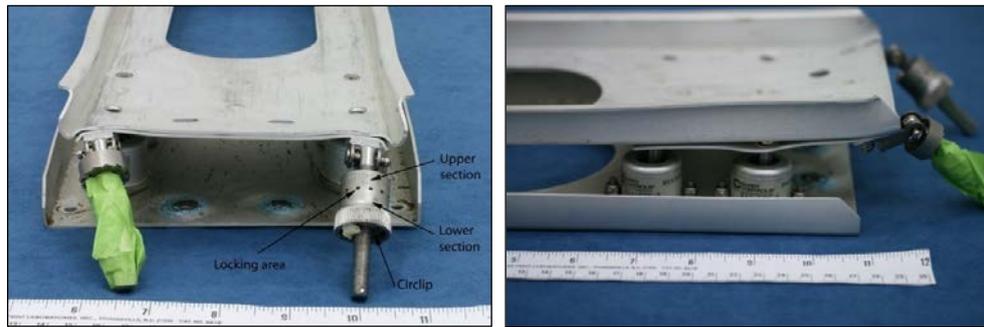
Examination of the FDR rack revealed moderate plastic deformation towards the front end of the rack, that is the end facing the rear of the aircraft (Figure A4).

**Figure A4: FDR rack as received**



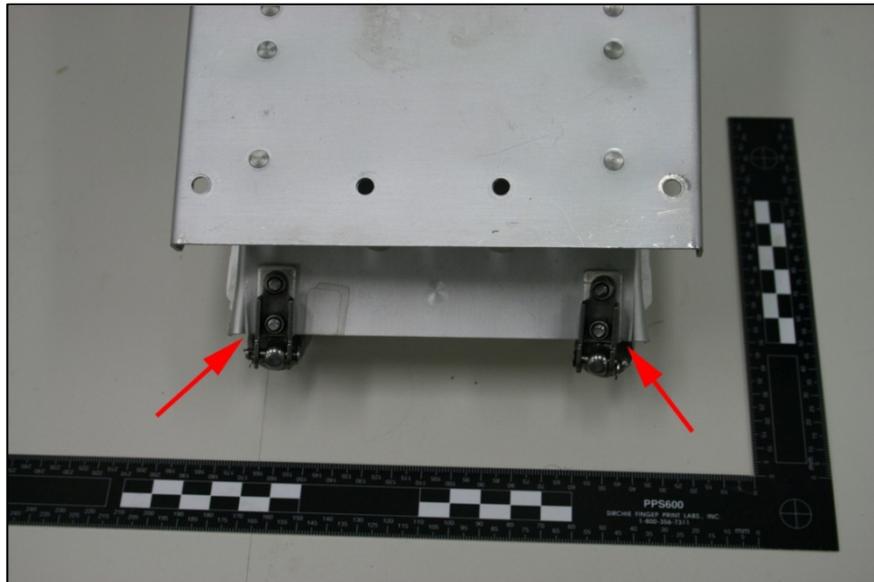
The upper shelf of the rack had deformed upwards, and some distortion across the width of the rack was also observed (Figure A5). The heads of the screws holding the upper tray in position had been pulled through their recesses.

**Figure A5: Magnified views of the damaged end of the FDR rack**



Plastic deformation was also observed on the underside of the upper tray in the areas adjacent to the fasteners (Figure A6). Note the plastic deformation appeared to have affected the upper tray of the rack only, displacing it upwards and outwards. No contact marks were evident on the underside of the rack or fasteners.

**Figure A6: Underside of rack showing deformation in the region adjacent to the fasteners**



A number of dimensional checks were performed on the rack. The length and base plate width measurements were generally consistent with the engineering diagram provided by the manufacturer. The height of the upper tray was also measured in several locations, with a permanent deformation of approximately 14mm recorded towards the front. Width measurements were taken at several locations along the upper tray and a variation observed along the length.

The left fastener was damaged, with the bottom section (including the spring and the circlip used to hold the spring in place) no longer attached to the assembly. The bottom section of the fastener, and the circlip were found in the rear fuselage, however the spring was not recovered. Yellow paint was observed on the outside surface of the nut, along with some minor scoring damage. The circlip and associated components were examined visually, but no evidence of damage to identify the failure mechanism was observed.

The recorder was placed in the rack to assess the location of the fasteners in relation to the hooks. While the pins could be inserted into the rear face of the unit, the FDR

did not sit flush with the upper plate due to the permanent deformation of the rack. As a result, the right fastener could not be secured over the hook on the front of the FDR in the as-received position. The threaded nut of the left fastener appeared to be further from the hook; however it should be noted that a full examination of the effectiveness could not be performed, as the spring loaded mechanism was not recovered.

### **A.3 Maintenance**

The documentation provided by the operator indicated that the FDR was installed in A6-ERG on 17 September 2008, following overhaul on 13 September 2008. The overhaul notes stated that the underwater locator beacon battery was replaced at this time.

Instructions and procedures for the FDR had only one line referencing the fastening mechanism during installation. The installation instruction stated, "Lift the fasteners and tighten the knurled nuts until the DFDR is correctly attached". The document had no reference to how tight the nuts should be fastened.

### **A.4 Conclusion**

The damage observed on the FDR rack was considered to be the result of the tailstrike event. The vertical forces from the impact, acting on the weight of the FDR unit, would have imparted sufficient load to the rack through the fasteners, to permanently deform the aluminium sheet of the upper tray. The upper tray exhibited permanent plastic deformation/buckling along the vertical axis, towards the fastener end, in the order of 14 millimetres.

With the upper tray deformed, the nuts would have been able to disconnect from the FDR hooks, leaving the unit unsecured. The deformation was observed to be equal on the left and right sides of the upper tray, which indicated that both fasteners were secured at the time of the occurrence.

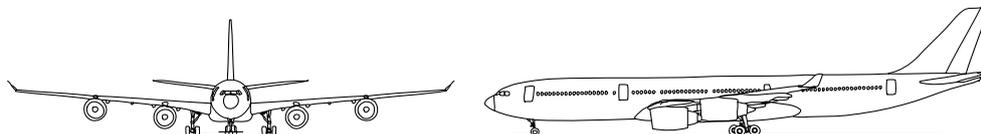
While a part of the left fastener had been separated from the rack (the spring assembly), the reason for the failure could not be determined.



# APPENDIX B : AIRCRAFT INFORMATION

## B.1 General

Figure B1: A340-541



Source: A340-500 FCOM Vol 1

The aircraft data at the commencement of the flight is listed in the following tabulated format.

Manufacturer	Airbus
Model	A340-541
Serial number	608
Registration	A6-ERG
Year of manufacture	2004
Certificate of registration	
Issuing authority	General Civil Aviation Authority United Arab Emirates
Issue date	30 November 2004
Certificate of airworthiness	
Issuing authority	General Civil Aviation Authority United Arab Emirates
Issue date	30 November 2004
Period of validity	30 November 2008 to 29 November 2009
Total airframe hours/cycles	22,526/2,598
Last maintenance check	11 March 2009
Next scheduled maintenance due	29 March 2009
Maximum certified take-off weight	372,000 kg
Maximum certified landing weight	243,000 kg
Maximum certified zero fuel weight	230,000 kg

## B.2 Engines

The aircraft was equipped with four Rolls-Royce Trent 553-61 high-bypass turbofan engines. Each engine was certificated at 270 kN (60,000 lb) thrust and de-rated<sup>1</sup> to 248 kN (55,780 lb) thrust for operation on the A340-500 series aircraft.

## B.3 Airworthiness

The Aircraft Technical Log entry for the flight indicated that a pre-flight inspection was completed at Melbourne by the ground engineers at 2130 in preparation for the flight to Dubai. The log noted 'nil defects' from the previous flight. A label on the overhead panel indicated that the No 2 high frequency (HF) radio transmitter was inoperative.

## B.4 Weight and balance

The following information, from the ACARS loadsheet (Appendix H), was transmitted to the flight crew at 1053:31 UTC:

Dry operating weight <sup>2</sup>	183,235 kg
Zero fuel weight	226,549 kg
Take-off fuel	135,300 kg
Take-off weight	361,849 kg
Fuel burn-off	125,300 kg
Landing weight	236,549 kg

The above weights were within the approved limits for the aircraft. The ACARS landing weight was for the intended landing at Dubai. The approximate landing weight at Melbourne following the accident was 280,000 kg.

Take-off centre of gravity was 27.1% of the mean aerodynamic chord<sup>3</sup>, and was within the approved limits for the aircraft.

## B.5 Overweight landing

Although the aircraft landed at a weight in excess of the maximum landing weight of 243,000 kg, the operator reported that an overweight inspection was not required in accordance with the Aircraft Maintenance Manual, as the vertical loads during the landing were less than 0.6 g.

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<sup>1</sup> De-rating an engine restricts the thrust output to a level below the potential maximum for the engine design.

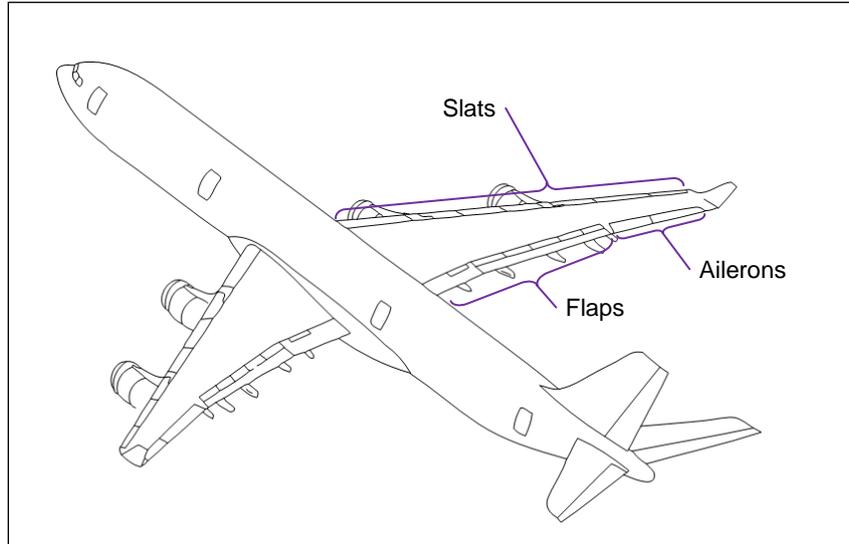
<sup>2</sup> The dry operating weight is the total weight of an aircraft for a specific type of operation, excluding the usable fuel and traffic load (cargo, passengers and bags).

<sup>3</sup> Mean aerodynamic chord. The chord of an imaginary wing of constant section that has the same force vectors under all conditions as those of the actual wing. The centre of gravity location is normally referenced relative to the mean aerodynamic chord.

## B.6 High lift devices

The aircraft was equipped with leading edge slats (slats) and trailing edge flaps (flaps) to increase the lift from the wings. The aircraft also drooped the ailerons (lowered their trailing edge) when the flaps were lowered to further increase the lift while maintaining lateral control (Figure B2).

**Figure B2: High lift devices**



Source: A340-500 FCOM Vol 1

The various configurations of flap, slat and aileron droop that were available to the crew are shown in Table B1.

**Table B1: High lift device configurations**

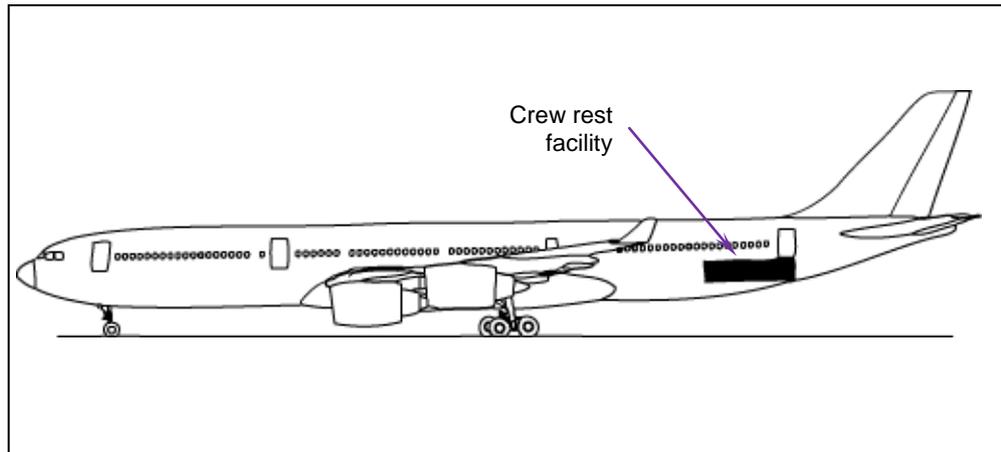
Lever Position	Slats	Flaps	Ailerons	Indication on ECAM	Flight Phase		
0	0	0	0				Cruise
1	21	0	0	1			Hold
		17	10	1 + F	Takeoff		
2	24	17	10	2			Approach
	24	22	10	2	Takeoff		
3	24	29	10	3		Landing	
FULL	24	34	10	FULL			

Source: A340-500 FCOM Vol 1

## B.7 Crew rest facility

The aircraft's crew rest facility provided an area for flight and cabin crews to rest during long duration flights that was separate from the passenger cabin. Air conditioned and located under the rear cabin floor (Figure B3), the rest area was accessed via a lockable door and ladder. It contained 10 bunk beds (two for flight crew and eight for cabin crew) and two seats. The *Flight Crew Operating Manual* noted that the facility was to be unoccupied during taxi, takeoff and landing.

**Figure B3: Crew rest facility location**



## **B.8 Flight Management and Guidance System**

### **B.8.1 General**

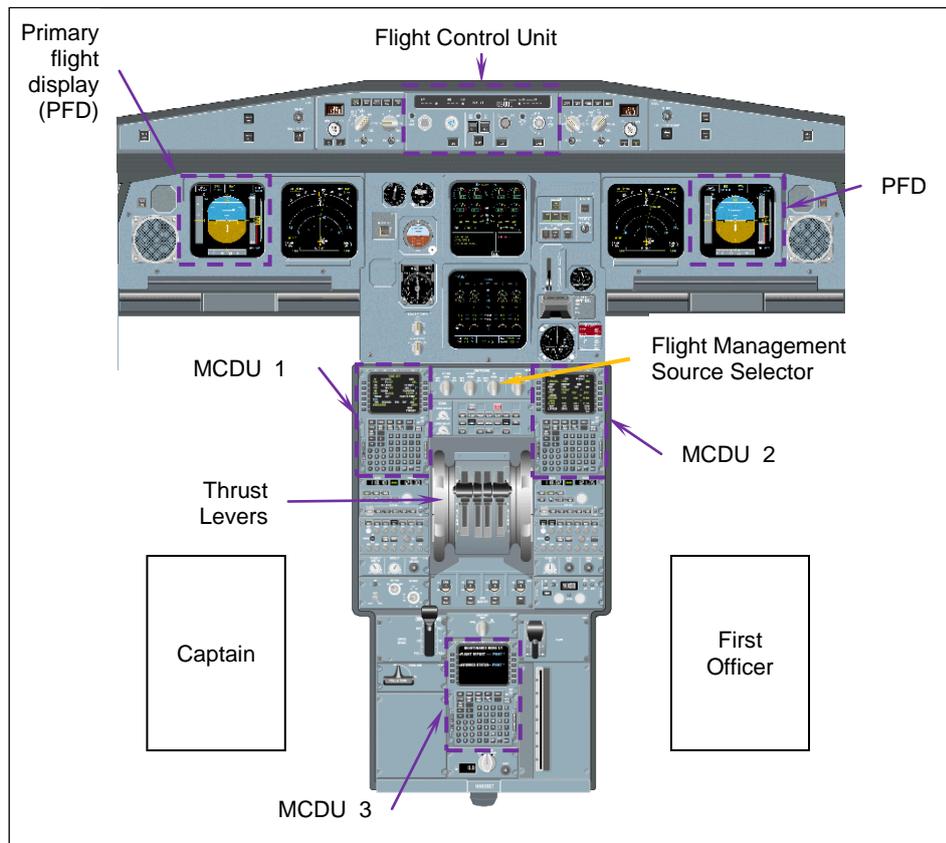
The aircraft's Flight Management and Guidance System (FMGS) is an integrated electronic system within the aircraft that performs navigation and flight planning (vertical and lateral) functions. By integrating with other aircraft systems, the FMGS can be used to guide the aircraft along a pre-planned flight path and performance profile. The FMGS consists of the following items (as shown in Figure B4)

- two Flight Management and Guidance Computers (FMGC), not shown
- three Multipurpose Control and Display Units (MCDU)
- one Flight Control Unit (FCU)
- one Flight Management Source Selector.

The FMGS also interfaces with the crew through the thrust levers and the Electronic Flight Instrument System (EFIS).

The FMGS provides for 'managed' and 'selected' flight guidance modes. Managed guidance is a long-term mode and will guide the aircraft along the flight plan route and profile. Selected guidance is a short-term mode that guides the aircraft to parameters entered by the flight crew on the FCU.

**Figure B4: Flight management and guidance system**



Note: example shown for illustration only and does not contain data from the accident flight

## **B.8.2 Flight Management and Guidance Computer**

The FMGC is a computer that contains databases of navigation waypoints, airline configuration data, aircraft performance models and magnetic variation. The flight crew build a flight plan (lateral route and vertical speed profiles) using the waypoints in the database and the FMGC calculates the targets (including speed, altitude and heading) required to guide the aircraft along that flight plan. The FMGC includes flight director, autopilot and autothrust functions used to guide the aircraft along the flight-planned route.

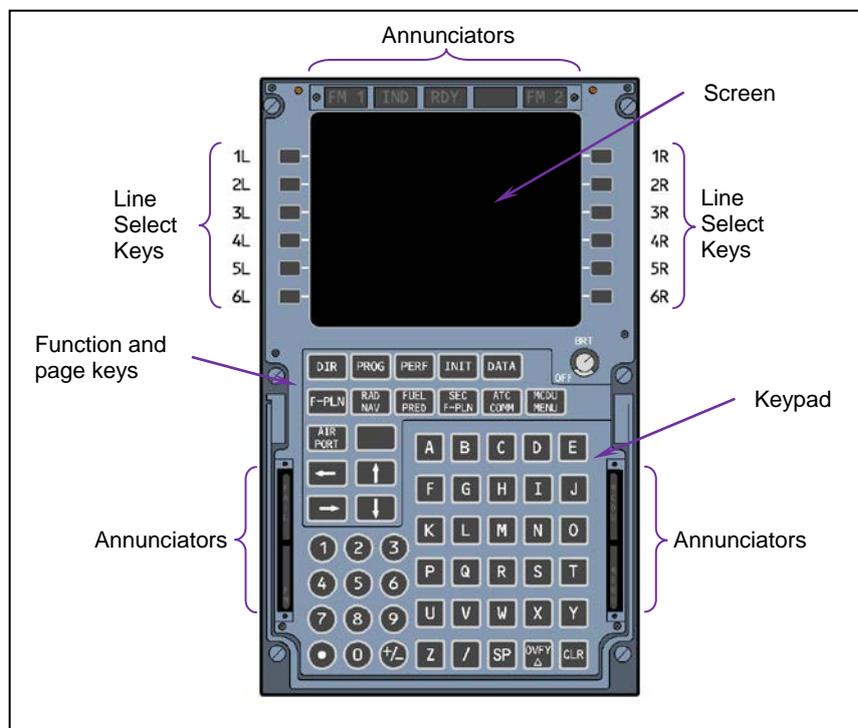
Incorporated into the FMGC are components for calculating and monitoring important flight envelope functions and a fault isolation and detection system. Included in the flight envelope functions is the calculation of characteristic speeds; such as the minimum flap retraction speed, the minimum slat retraction speed, and the green dot speed.

## **B.8.3 Multipurpose Control and Display Units**

Three MCDUs are located in the centre pedestal between the flight crew and provide the primary interface between the FMGS and the flight crew. The MCDU is used by the flight crew to enter and review data from the FMGC, allowing them to build and select flight plans and to maintain other flight management functions.

The MCDU contains a screen for presenting FMGC information, a keypad, to allow the flight crew to navigate through the various pages and enter and modify data, and status annunciators (Figure B5).

**Figure B5: Multipurpose Control and Display Unit**



### B.8.4 Determination and presentation of the take-off weight

The take-off weight for the aircraft is the zero fuel weight plus the block fuel. The flight crew enter the zero fuel weight (and zero fuel weight centre of gravity) and the block fuel, in tonnes, into the INIT B page (second page of the initialisation pages) on the MCDU (Figure B6). The FMGC then adds the figures and presents the take-off weight to the crew.

**Figure B6: FMGS INIT B page**



Note: example shown for illustration only and does not contain data from the accident flight

The aircraft's current gross weight (GW) and gross weight centre of gravity position (GWCG) were calculated by the FMGS and permanently displayed on the electronic centralised aircraft monitor (ECAM) lower system display (Figure B7). These values changed as fuel was burnt off.

**Figure B7: ECAM system display - Gross weight and centre of gravity**

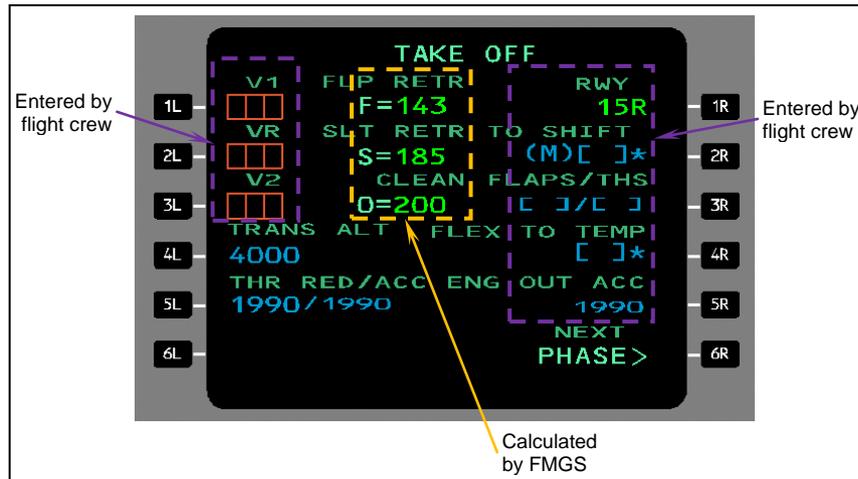


Note: example shown for illustration only and does not contain data from the accident flight

## B.9 Take-off performance information

The information used by the flight crew and aircraft during the takeoff includes data that is manually entered into the FMGS PERF [performance] TAKE OFF page by the flight crew, or that is calculated by the FMGS (Figure B8). The FMGS PERF TAKE OFF page is only available during the pre-departure phase.

**Figure B8: FMGS PERF TAKE OFF page**

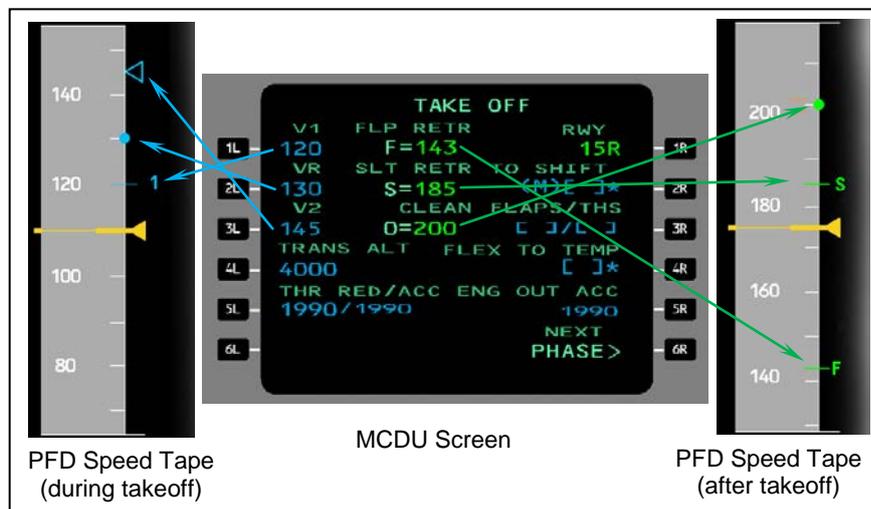


Note: example shown for illustration only and does not contain data from the accident flight.

The flight crew enter the take-off reference speeds ( $V_1$ ,  $V_R$ , and  $V_2$ ), runway number, take-off shift (if the takeoff is not from the beginning of the runway), the take-off flap setting, the trimmable horizontal stabiliser (THS) setting, the flexible take-off temperature and the engine out acceleration altitude.

The take-off reference speeds, minimum flap retraction speed (F), minimum slat retraction speed (S) and green dot speed (O) are also displayed on the speed tape on the primary flight display (Figure B9). There is also an automated audible message of  $V_1$  during the take-off run.

**Figure B9: Take-off reference speeds displayed on PFD**



Note: Example shown for illustration only and does not contain data from the accident flight.

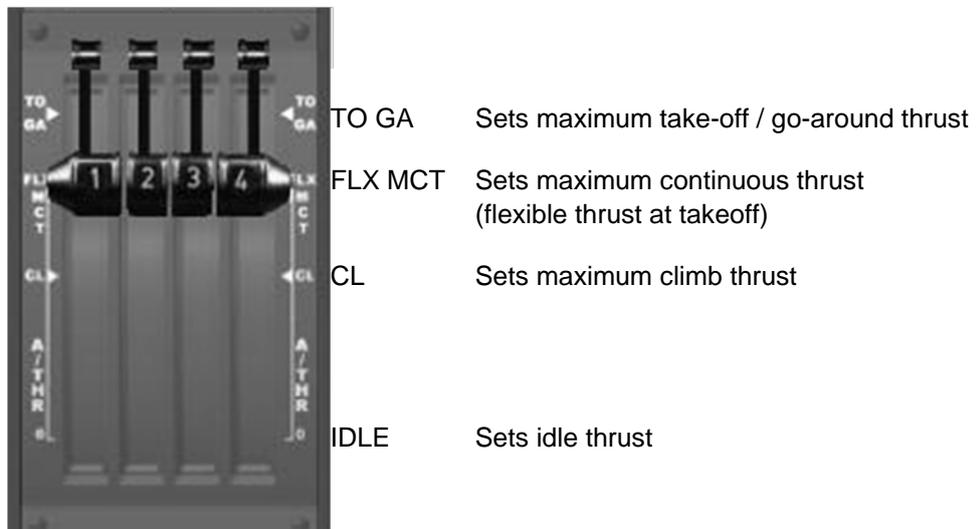
## B.9.2 Thrust Levers

The Flight Guidance component of the FMGS includes an autothrust feature. When the autothrust feature is engaged, the FMGC will determine the required thrust and send the appropriate thrust command to the engine control systems. The thrust levers provide an interface between the flight crew and the thrust management/engine control systems. The thrust levers are used to:

- manually select the engine thrust
- arm and activate the autothrust
- engage reverse thrust
- engage take-off and go-around mode.

The thrust levers can be set at any position within their range (setting either the desired thrust or the maximum thrust delivered by the autothrottle), but the thrust lever quadrant also has four detent positions (Figure B10).

**Figure B10: Thrust levers**



## B.10 Return to service

Following the accident, the aircraft was inspected by engineers from the aircraft manufacturer and temporary repairs were carried out in Melbourne before it was ferried, unpressurised, to Toulouse, France. Permanent repairs were completed by the manufacturer and the aircraft returned to service in December 2009.



# APPENDIX C : GRAPHICAL REPRESENTATION OF RECORDED FLIGHT DATA

Two plots of the relevant flight data from the digital aircraft condition monitoring system recorder (DAR) were prepared and are at Figure C11 and C12.

Figure C11: Selected DAR parameters for the take-off roll

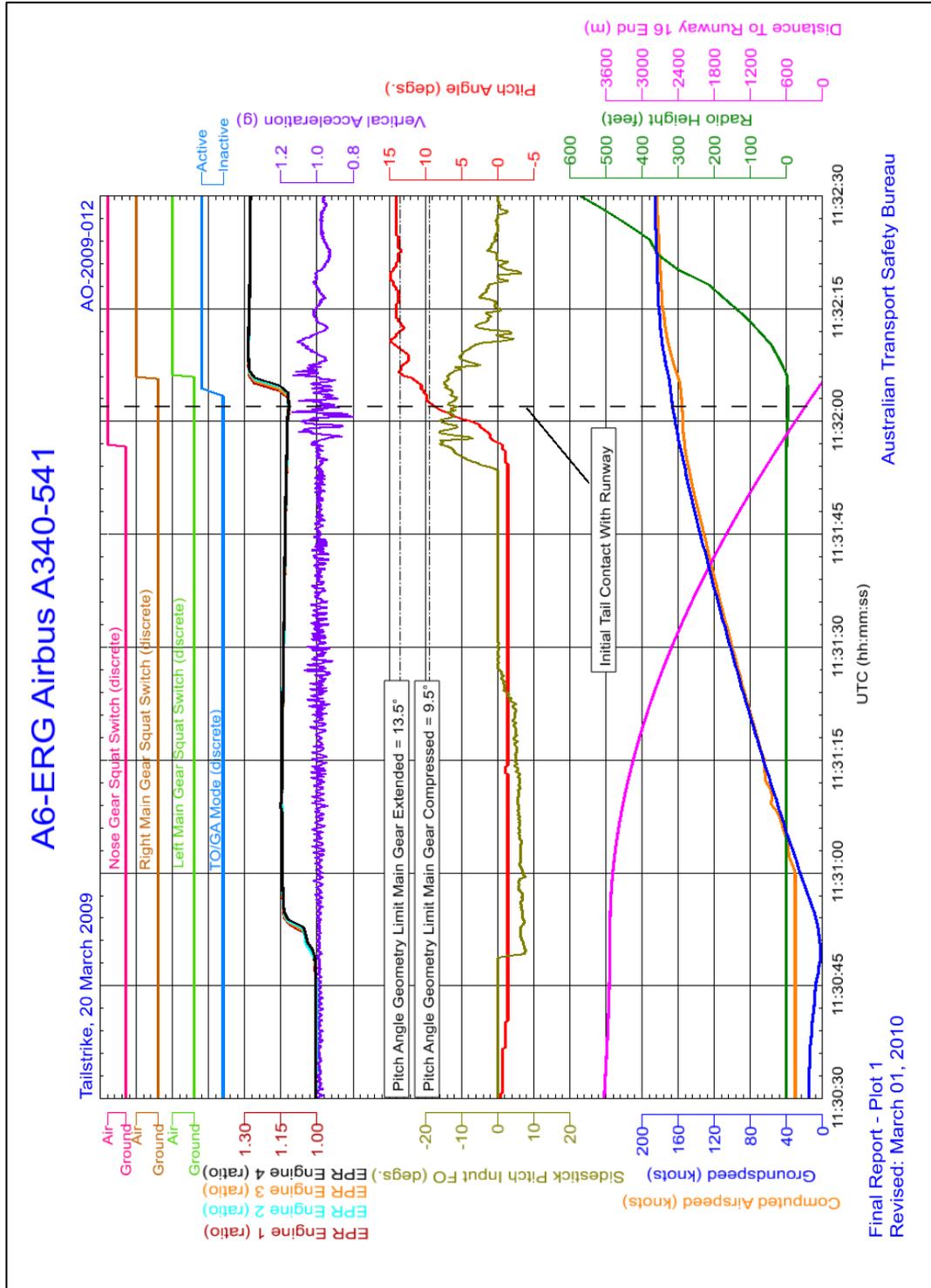
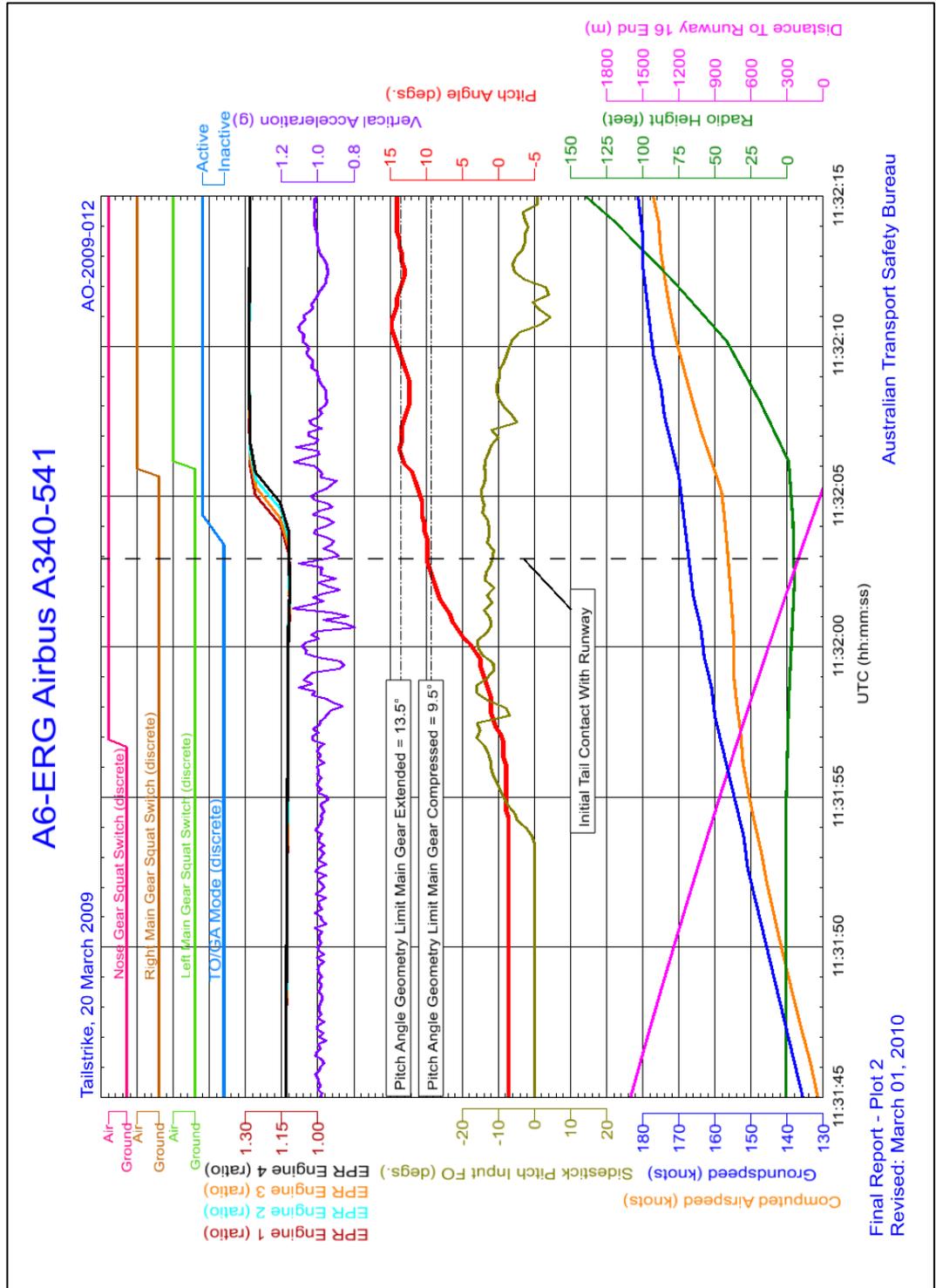


Figure C12: Selected DAR parameters for the 30 seconds surrounding lift-off



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## APPENDIX D : DETAILED REVIEW OF SIMILAR OCCURRENCES TO THE ACCIDENT

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The investigation used the research from the Australian Transport Safety Bureau safety research report AR-2009-052 *Take-off performance calculation and entry errors: A global perspective*, and the Laboratoire d'Anthropologie Appliquée report *Use of Erroneous Parameters at Takeoff* to identify those events which shared multiple similarities with the accident.

Details of these events, including explanation of the event to provide the context of the error and subsequent use of erroneous data, are reproduced below.

### ***McDonnell Douglas DC-8: March 1991***

Location: New York, United States

In preparation for takeoff, the flight engineer calculated the take-off reference speeds (or V speeds) and horizontal stabiliser trim setting. The captain and first officer did not confirm the data. During the takeoff, the captain (the pilot flying) noticed that the force required to rotate was greater than normal and that at the V speeds calculated, the aircraft would not fly. In response, the captain rejected the takeoff. The crew were unable to stop the aircraft within the remaining runway length. The aircraft struck the instrument landing system equipment, the landing gear collapsed and all four engines were torn away.

It was determined that the flight engineer calculated the take-off performance data based on a take-off weight (TOW) of 242,000 lbs (109,771 kg) instead of 342,000 lbs (155,131 kg).

### ***Boeing B767: August 1999***

Location: Copenhagen, Denmark

The first officer entered the runway in use, temperature, and other flight details into the aircraft communication addressing and reporting system (ACARS). The TOW was not entered because the flight crew had not yet received the loadsheet. Once the loadsheet arrived, the captain entered the zero fuel weight (ZFW)<sup>95</sup> into the FMS. The first officer then entered the ZFW into the aircraft TOW prompt in ACARS. The calculations were made at the mainframe computer and sent back via ACARS to the flight crew.

The relief pilot noticed that the mean aerodynamic chord (MAC) was 7.0%, which did not appear to be correct. According to the loadsheet, the MAC was 19.0%. The first officer amended the ACARS accordingly. The captain entered the V speeds into the FMS.

During the takeoff, the tailskid pan came into contact with the runway, the aircraft failed to become airborne and the captain rejected the takeoff.

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<sup>95</sup> The zero fuel weight is the total weight of an aircraft for a specific type of operation including the traffic load (cargo, passengers and bags), but excluding the usable fuel.

It was determined that the first officer had limited experience on the B767 but had previously flown the McDonnell Douglas MD-80, where the ZFW was the take-off input parameter. The flight crew did check the performance data, however their attention was drawn to the MAC and not the TOW and V speeds. The layout of the ACARS print out could have resulted in a misinterpretation of the TOW, with the crew possibly believing they had 'found the value they were looking for' but at the wrong location. In addition, the flight crew's normal procedures may have been interrupted by the relief pilot observing the MAC value discrepancy which, in turn, may have stopped them from checking the remaining take-off data.

***Airbus A330: June 2002***

Location: Frankfurt, Germany

While preparing the aircraft for the flight, the crew received the initial load figures from the ACARS and entered the TOW (222,700 kg) and V speeds into the MCDU. Shortly after, the crew received the final load figures with a revised TOW of 221,200 kg. During pushback or taxi, the pilot not flying inserted the final load figures and V speeds into the MCDU. When doing so, a  $V_1$  speed of 126 kts was entered instead of 156 kts. The crew did not detect the error and during takeoff, aircraft rotation was initiated at 133 kts. Due to over rotation the aircraft sustained a tailstrike.

***Boeing B747: March 2003***

Location: Johannesburg, South Africa

During flight preparations, the crew were distracted by a problem with the auxiliary power unit. They were also advised by ATC to expect a 45-minute delay, subsequently reduced to a 30-minute delay.

The flight engineer received the aircraft loadsheet and inadvertently entered the ZFW into the handheld performance computer instead of the TOW. The resultant V speeds were transferred onto the take-off data card. The captain checked the V speeds because the first officer, who normally conducted this check, was busy. Both pilots set the speed bugs on their respective airspeed indicators. During the takeoff, the captain sensed that the aircraft was nose heavy. In response, rotation was delayed by 15 kts. After becoming airborne, the captain felt the aircraft was sluggish and requested more thrust. The crew were notified by ATC that the aircraft had sustained a tailstrike.

***Boeing B747: March 2003***

Location: Auckland, New Zealand

During early pre-departure preparations, the flight crew determined that additional 7,700 kg fuel would be required to that already on the aircraft. When they boarded the aircraft about 15 minutes prior to departing, they realised that only 4,500 kg had been uploaded. They requested the additional fuel be loaded and obtained a revised loadsheet. The final loadsheet was delivered to the flight crew about the same time the aircraft was scheduled to depart.

The captain called out the ZFW and TOW figures and the stabiliser trim setting for the first officer to write on the take-off data card. During this transcription, the first

officer recorded the TOW as 247,400 kg instead of the actual TOW of 347,400 kg. The first officer normally added the ZFW to the fuel figure to verify the TOW, however on this flight he either added them incorrectly or did not get a chance to add them together during this stage of the pre-departure phase of flight.

The first officer used the TOW of 247,400 kg to obtain the V speeds for takeoff and then passed the take-off data card to the captain. The captain entered the ZFW from the loadsheet into the flight management computer (FMC). The FMC automatically added the ZFW to the onboard fuel weight to display a gross weight. The captain verified that the FMC-calculated gross weight corresponded to the TOW from the loadsheet (which it did). He then entered the V speeds from the take-off data card, replacing those automatically calculated by the FMC.

Normally the third relief pilot would check the take-off data card, however he was distracted by explaining the delay to the station manager and did not complete this check. During the takeoff, the aircraft sustained a tailstrike.

The investigation determined that, in addition to the errors noted above, the flight crew were pressured to hurry their preparations due to the delay with refuelling; that the captain had only recently converted to the B747 from the A340, which had a  $V_R$  speed range which matched the incorrect  $V_R$  speed calculated for the accident flight; there were no specific duties for the relief, or third, pilot; and the FMC did not challenge the discrepancies between the V speeds it had calculated and what the pilot entered, despite the difference being in the order of 20 kts.

### ***Boeing B747: October 2003***

Location: Tokyo, Japan

The aircraft was being prepared for departure as a cargo flight, with a captain, first officer training as a first officer, a flight engineer and the first officer. Upon arriving at the aircraft, the flight engineer noted the loading was behind schedule. The flight engineer obtained the weight and balance manifest from the load planner and prepared the take-off data card. When obtaining the V speeds from the take-off performance charts, he inadvertently used a TOW of 550,000 lbs (249, 480 kg) instead of the actual TOW of 745,000 lbs (337, 932 kg). Due to the flight being behind schedule, the flight engineer did not verify the accuracy of the figures, because this would have delayed the flight further.

During the takeoff, the aircraft did not respond during rotation and sustained a tailstrike. The investigation determined that while the flight engineer made the error, the captain, training pilot and first officer did not suspect or crosscheck the figures. The training pilot stated the weight always used in the simulator was 530,000 lbs and that, in addition, he had previously used kilograms as a unit of measurement and did not immediately detect the mistake in the numbers.

### ***Airbus A340: July 2004***

Location: Paris, France

During pre-departure preparation, the flight crew were given an expected TOW figure of 268,600 kg, which they rounded to 270,000 kg and used to submit a take-off data calculation request from Flight Operations via ACARS. The resultant take-off performance parameters were verified by the flight crew.

Shortly after, the flight crew were advised that the actual TOW was 5,200 kg less than the expected, resulting in a TOW of 264,800 kg. As the change was greater than 5,000 kg, the crew were required to submit a new ACARS request. When they entered the revised TOW into the flight management and guidance system (FMGS) interface, a weight of 165,000 kg, which was close to the ZFW, was inadvertently entered. The resultant V speeds and FLEX temperature values were entered into the FMGS. The captain confirmed the parameters, however, he did not detect the error because he read the MTOW from the ACARS printout instead of the TOW.

The pilot flying reported that, during the takeoff the aircraft felt heavy and noticed the  $V_2$  speed was slower than the lowest selectable speed. The aircraft sustained a tailstrike on rotation.

The investigation noted that the FMGS accepted the lower V speeds without challenge and did not compare the  $V_2$  figure with the lowest selectable speed, despite both being known before takeoff. In addition, the layout of the ACARS values may have led to confusion between TOW and ZFW and the take-off briefing procedures did not require a comparison between the TOW and speed characteristics.

#### ***Boeing B747: October 2004***

Location: Halifax, Canada

The aircraft was to be operated as a cargo flight with two captains, one first officer, two flight engineers, a loadmaster and a ground engineer. During takeoff the rear fuselage came in contact with the runway momentarily and then again with greater force. Despite becoming airborne past the end of the runway, the aircraft struck an earth embankment supporting the instrument landing system antenna, and then the terrain, resulting in the aircraft being destroyed by impact forces and a subsequent fire. All seven of the crew members received fatal injuries.

The investigation determined that the take-off data calculated in the Boeing Laptop Tool (BLT) was nearly identical to the take-off data from the previous airport and not what was required for the takeoff from Halifax. It was likely that an independent check of the take-off data card was not performed by the crew as required by procedures, nor was a gross error check conducted in accordance with procedures. In addition, the crew were at a low level of performance due to fatigue which degraded their ability to detect the error and the dark take-off environment contributed to a loss of situational awareness.

#### ***Airbus A340: August 2005***

Location: Shanghai-Pudong, China

About 30 minutes prior to the scheduled departure, the crew received the preliminary load information via the ACARS with a ZFW of 179,110 kg and a TOW of 259,514 kg. The captain was temporarily away from the cockpit so pre-departure preparations had been delegated to the second officer. When entering the data into the ACARS take-off data calculation (TODC) computer, the ZFW was entered instead of the TOW. Soon after, the final loadsheet was received and the TODC was not updated.

When the captain arrived, the majority of the pre-flight preparations had been completed. The captain checked the loadsheet and flight plan and the second officer

read out the TODC speeds to the captain, who entered them into the MCDU. The captain observed the difference between the  $V_1$  and  $V_R$  speeds were small, but no further action was taken. The captain believed the last line of defence was incorporated into the ACARS TODC, similar to that previously experienced when he had flown the Boeing 767.

The captain and first officer verified the take-off data calculations prior to departing the gate and while taxiing, but the error was not detected. During the takeoff, the aircraft did not lift off as expected, the fuselage contacted the runway and take-off/go-around (TO/GA) thrust was applied by the first officer at the same time the aircraft became airborne.

The investigation determined that the second officer did not have immediate access to the flight plan to confirm the aircraft's TOW and the captain had been temporarily pre-occupied. The ACARS TODC computer required input of the TOW, while the MCDU required input of the ZFW. All crewmembers were previously qualified on the Boeing 767 aircraft where the TOW was similar to the ZFW of an A340. The data was entered into the TODC computer using a third MCDU which was not visible to the other two crewmembers. The captain and first officer were also qualified on the Airbus A330, where the V speeds and thrust settings are lower than that of the A340. The V speeds were verbally provided to the pilot flying; the printed calculations were not shown. The ACARS TODC software accepted unrealistic low weights and mismatched V speeds without challenge. The duties of the second officer were not clearly defined by the airline.

### ***Boeing B747: December 2006***

Location: Paris, France

When determining the take-off performance parameters for the flight, the captain provided the first officer with a ZFW from the weight and balance sheet, which he increased by 1.6 tonnes, and the TOW. The first officer then entered the ZFW into the FMS. The TOW was entered into the BLT and the take-off performance parameters calculated. The first officer handed the BLT to the captain to crosscheck and when the captain handed it back, the first officer unintentionally turned off the laptop, erasing the data. At the same time, the captain was dealing with a mechanic in the cockpit regarding a systems failure.

When the new data was being entered into the BLT, the captain inadvertently called out the ZFW instead of the TOW, resulting in a weight of 242,300 kg being entered into the BLT as TOW, instead of 341,300 kg. The captain entered the resultant data into the FMS, replacing the values automatically calculated by the FMS. The first officer verified the BLT and FMS values were identical. The captain queried the reduced thrust value with the first officer, who justified these figures by the fact the QNH (barometric air pressure) was high and ambient air temperature was low.

The crew did not detect the aircraft's acceleration was lower than normal; however at the  $V_1$  speed they noted a reasonable amount of runway remaining and they began to doubt the V speeds, resulting in the captain delaying rotation. When rotation was initiated by the first officer, he felt the aircraft was heavy and pitched up slowly, followed by activation of the aircraft's stick shaker. He reduced the pitch up command and applied full thrust.

The investigation determined that the captain was dealing with a hydraulic failure at the time the performance calculations were taking place and after the data was

entered into the FMS, there was no requirement for a comparison to be made with the TOW. There was also no requirement to compare data entered into the BLT with the data entered into the FMS.

### ***Airbus A330: October 2008***

Location: Montego Bay, Jamaica

During pre-departure preparations, the crew were unable to locate the aircraft's performance manual. The captain contacted the flight dispatch department via telephone to request that the take-off performance data be calculated and relayed the relevant information. The resultant figures were read back to the captain, the telephone was then passed to the first officer and this process repeated as a check. The figures were then entered into the FMGS.

During takeoff, the aircraft appeared to accelerate as normal, however the aircraft did not 'feel right' at rotation, so the captain applied TO/GA thrust and the aircraft became airborne and climbed away.

While the exact source of the error could not be identified, the investigation determined that a TOW of 120,800 kg was used by the dispatcher instead of 210,183 kg, resulting in V speeds which were too low for the aircraft's actual weight. The procedure for calculating and verifying the calculations was not completely carried out, as a second dispatcher was not used to verify what was entered by the first dispatcher.

### ***Boeing 767: December 2008***

Location: Manchester, United Kingdom

During calculation of the take-off performance parameters, the crew inadvertently entered the ZFW instead of the TOW. The calculated V speeds and thrust setting were then entered into the FMC. The aircraft left the gate about 15 minutes behind schedule.

While taxiing, it began to rain heavily and the engine anti-ice was required to be on. Accordingly, the first officer re-calculated the V speeds and informed the captain there was no change. The crew's attention was focussed on the taxi, due to works in progress on some taxiways.

During takeoff, the captain noted the aircraft had sluggish acceleration and delayed the V<sub>1</sub> call. Upon rotation the tailskid message illuminated, indicated the aircraft had sustained a tailstrike.

The investigation determined that the captain had flown a number of sectors in an empty Boeing 767 prior to the accident flight, consequently the slow V speeds did not trigger an alert to him. The crew were distracted by the works in progress on the taxiways and the delay in departing led to a time pressure on the crew.

# APPENDIX E : OPERATOR'S PROCEDURES FOR CALCULATING TAKE-OFF PERFORMANCE

<b>A340 -500</b> <small>Flight Crew Operating Manual</small>	STANDARD OPERATING PROCEDURES  COCKPIT PREPARATION	3.03.06	P 17 A
		<b>REV 31</b>	

## **REVISED ZFW DATA RECEIVED**

Following receipt of revised ZFW data from station personnel, the crew will correct OFP TRIP, RRSV, as well as any other applicable fuel item and calculate a revised RAMP FUEL figure. This figure, along with TRIP and TAXI fuel figures should be communicated to station staff for Loadsheets computation purposes. The revised RAMP FUEL figure shall then be communicated to ground refuelling personnel.

\*- **REVISED DATA (INIT B PAGE) ..... INSERT** CM1

If updated values are available:

- In the ZFW field, check/modify the estimated ZFW
- In the BLOCK field check/modify the estimated Block fuel
- Modify any other field as applicable

\*- **TAKEOFF PERFORMANCE DATA ..... CALCULATE** CM2

The preferred method of takeoff calculation is the laptop. If the laptops are unserviceable or unavailable, contact Ops Control.

Using the appropriate tail number, airport, runway, ambient conditions, CG, TOW displayed on the INIT B page, and flap setting (when using the laptop, the default is OPTIMUM and this default flap setting should be used unless contrary, specific company guidance has been issued) obtain the calculation result. The data required is: Result TOW, FLEX [TOGA], V1, VR, V2 and engine-out procedure / acceleration altitude.

On the Master OFP, CM2 records the calculation runway, CG, Result TOW, FLEX [TOGA], V1, VR, V2, Flap CONF, engine-out acceleration altitude and engine-out procedure.

\*- **TAKEOFF PERFORMANCE ERROR CHECK ..... PERFORM** BOTH

CM1 crosschecks that the correct tail number, a/c type, airport, runway, chosen flap setting, ambient conditions CG and TOW (from INIT B page) were used to calculate the Result TOW, V1, VR, V2, engine-out acceleration altitude and FLEX temperature.

CM1 states the Result TOW and the TOW displayed on the INIT B page.

**(See Section 3.03.91 Briefing Guide - Takeoff Performance Error Check - Takeoff Weight Check).**

Both confirm that the TOW on the INIT B page is less than or equal to the result TOW.

ALL

**FMGS DATA INSERTION**

Select the PERF TAKE OFF page.

Use the information displayed on the RESULTS panel (laptop).

CM1 shall confirm that the runway displayed on the PERF TAKE OFF page is the same runway used for the takeoff performance calculation.

\*- **FLAPS/THS REMINDER** ..... **INSERT FLAPS** ..... CM1

\*- **FLEX TO TEMP** ..... **INSERT** ..... CM1

\*- **ENG OUT ACC altitude** ..... **SET or CHECK** ..... CM1

\*- **V1, VR, V2** ..... **INSERT** ..... CM1

**DATA ENTRY CONFIRMATION**

\*- **DATA ENTRY CONFIRMATION** ..... **PERFORM** ..... BOTH

CM1 states the following from the PERF TAKE OFF page:

RWY, FLAPS, FLEX [TOGA], ENG OUT ACC, V1, VR, V2

CM2 compares stated figures with data previously recorded on the Master OFP

(See Section 3.03.91; Briefing Guide - Takeoff Performance Data Entry - Data Entry Confirmation)

**BEFORE PUSHBACK or START**

- **LOADSHEET DATA** ..... **CHECK/ENTER** CM1

  - \* Check the Loadsheet in accordance with OM-A/FOM.
  - \* Select the INIT B page.  
 Compare ZFW/ZFWCG with previously entered data and adjust if necessary.  
 Enter the MACZFW value from the loadsheet into ZFWCG field.
  - \* Confirm that BLOCK fuel agrees with the FOB value displayed on the ECAM E/WD.
  - \* Check loadsheet CG against ECAM CG.  
 In case of discrepancy of more than 2%, check that the ZFW and ZFWCG have been correctly inserted in the MCDU. Resolve any anomaly with loadsheet.  
 If the difference is less than 2%, no further action is required. Rely on ECAM CG.
  
- **TAKE-OFF DATA** ..... **CHECK/REVISE IF RQRD** BOTH

If the TOW displayed on the INIT B page is greater than that (as recorded on the Master OFP) which was initially used to calculate V speeds and FLEX temperature, a new performance calculation shall be performed and the checking procedure shall be repeated.

  - Check loadsheet CG versus ECAM CG. **Check ECAM CG is appropriate for T/O Performance calculations.**
  - Select the PERF TAKE OFF page.  
 Enter the STAB setting from the Loadsheet into the THS field. **The entered THS value will be used to trigger the PITCH TRIM/MCDU/CG DISAGREE caution, if appropriate.**
  
- **LOADSHEET CONFIRMATION PROCEDURE** ..... **PERFORM** BOTH

**(See Section 3.03.91 Briefing Guide - Loadsheet Confirmation Procedure).**  
 CM2 need only record the following Loadsheet values on the Master OFP:  
 number of Crew, number of passengers, total number of people on board, DOW, DOI and AZFW.
  
- **MCDU** ..... **IN TAKE-OFF CONFIGURATION** BOTH

It is recommended that the crew displays F-PLN on the PNF side and PERF TAKE-OFF on the PF side.
  
- **SEATS, SEAT BELTS, HARNESSSES, ..... ADJUST** BOTH

**RUDDER PEDALS, ARMRESTS**  
 The seat is correctly adjusted when the pilot's eyes are in line with the red and white balls.

ALL

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### **TAKEOFF PERFORMANCE ERROR CHECK**

The following is an example of verbal communications associated with two mandatory error checks of takeoff performance data entry prior to departure:

- **Takeoff Weight Check:** comparison of calculated Result takeoff weight with MCDU *INIT B* page predicted *TOW*.
- **Data Entry Confirmation:** comparison of displayed MCDU *PERF* page data with data previously transcribed onto the Master OFF.

EVENT	CM1	CM2	REMARK
<b>GROSS ERROR CHECK</b> Takeoff Weight Check	"The <i>FLEX 56 [TOGA]</i> limiting weight is 226.5 Tonnes. That compares with an FMS predicted takeoff weight of 226.5 Tonnes"		*If using Laptop: CM1 states the Laptop <b>RESULTS Weight</b> (normally highlighted in blue - displayed in lower right corner of Laptop screen) and states the displayed <i>INIT B</i> predicted <i>TOW</i>  *If using RTOW chart: CM1 states Result Weight previously transcribed onto Master OFF and states the displayed <i>INIT B</i> predicted <i>TOW</i>  Result Weight must not be less than <i>INIT B</i> predicted <i>TOW</i>  CM2 confirms and announces
Data Entry Confirmation	"Runway 12 Right, Config 1+F, <i>FLEX 56</i> , Engine out acceleration altitude 1100 ft. V1: 155, VR: 158, V2: 162"	"Checked"	CM2 compares announced data with data previously recorded on Master OFF and announces

Following this, CM1 must perform the following:

TASK	CM1	WHEN
<b>Notation of Takeoff Performance RESULT Weight and associated Green Dot speed</b>	CM1 notes the RESULT weight from the takeoff performance calculation and obtains the Green Dot speed associated with this weight, from QRH 4.01 or LPC TO program (when available). CM1 shall transcribe these values onto his copy of the OFF.	Following Data Entry Confirmation

ALL

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	BRIEFING GUIDE	REV 31	

### **LOADSHEET CONFIRMATION PROCEDURE**

After the Loadsheets arrives, CM1 shall confirm that: correct flight number, departure and destination stations, correct aircraft and date, are listed on the Loadsheets. CM1 will then enter Loadsheets values for ZFWCG/ZFW into the MCDU *INIT B* page and a confirmed *THS* value into the *PERF TAKEOFF* page.

**CM1 must note the *TOW* value displayed on the *INIT B* page and ensure it does not exceed the *RESULT* weight from the Takeoff Performance calculation.**

The following example illustrates communication that should then occur.

TASK	CM1	CM2	REMARK
CM1 announces pertinent Loadsheets figures to CM2	"Crew 15, passengers 228"  "Dry Operating Weight 127.1"  "DOI 100.2"	"Total 243"  "In range"  "In range"	CM2 need only record these figures on the Master OFP. No other Loadsheets figures need be transcribed, with the exception of AZFW at the end of this procedure.  Flight plan printed DOW and DOI ranges are advisory only, not limits.
<b>CM2 then reads aircraft indicated figures to CM1, starting with the top right-hand corner of the MCDU <i>INIT B</i> page.</b>			
Confirmation of Zero Fuel Weight	"Checked"	"ZFW 167.1"	CM2 reads from <i>INIT B</i> page. CM1 checks Loadsheets. Resolve discrepancies.
Confirmation of Take Off Weight	"Checked"	"TOW 226.4" "Calculated FLEX [TOGA] Limiting Takeoff Weight was 226.5"	CM2 and CM1 must compare <i>TOW</i> with <i>RESULT</i> weight previously obtained from the Laptop/RTOW Chart. Takeoff performance calculation ( <i>FLTOW</i> on OFP is the Flex Limiting Take Off Weight)
<b>GROSS ERROR CHECK</b> Confirmation of Landing Weight	"Checked"	"LW 175.0"	Figures should typically be within Three Tonnes of each other. A discrepancy outside of this value should be resolved prior to departure.
CM2 announces Aircraft indicated data to CM1	"Checked" "Checked, within Two percent" "Checked"	"ZFWCG 29.9" "ECAMCG 28.3" "THS 3.3 UP"	
<b>GROSS ERROR CHECK</b> Comparison of <i>PERF TAKEOFF</i> Green Dot "0" speed with external reference	"Checked within two knots"	" <i>PERF</i> Green Dot 244 knots"	CM2 reads Green Dot Speed from <i>PERF TAKEOFF</i> page. CM1 refers to Green dot speed previously obtained from QRH 4.01 or LPC TO program (when available). A speed difference of Three knots or more between sources indicates that a weight-input discrepancy exists ( <i>PERF TAKEOFF</i> page indicated Green Dot speed varies with pilot weight inputs to the <i>INIT B</i> page). Resolve discrepancies.
Independent & silent check of printed Loadsheets figures		"Loadsheets Checked"	CM2 observes printed Loadsheets figures and transcribes AZFW to the Master OFP.

ALL



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## APPENDIX F : PREVIOUS RECOMMENDATIONS RELATING TO THE MONITORING OF TAKE- OFF PERFORMANCE

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### F.1 Introduction

There have been a number of accidents and incidents involving civil transport aircraft relating to the monitoring of take-off performance.

The occurrences summarised below represent some of the accidents involving high capacity aircraft and the associated safety recommendations from investigation agencies relating to the monitoring of take-off performance.

This appendix also discusses the current status of the research and development of take-off performance monitoring systems (TOPMS) by various organisations.

### F.2 Occurrences and recommendations

#### ***McDonnell Douglas DC-8: November 1970<sup>1</sup>***

Location: Anchorage, United States (US)

On 27 November 1970 a McDonnell Douglas DC-8-63F, registered N4909C, with 10 crew and 219 passengers, overran runway 06R at while taking off at Anchorage International Airport, Alaska. The overrun was determined to be due to high frictional drag caused by all main landing wheels not rotating. This resulted in 46 passengers and one cabin crew member sustaining fatal injuries, and the destruction of the aircraft.

As a result of this accident, on 20 January 1971 the US National Transportation Safety Board (NTSB) issued the following recommendation to the US Federal Aviation Administration (FAA):

Federal Aviation Administration determine and implement takeoff procedures that will provide the flight crew with time or distance reference to enable him to make appropriate judgment with regard to the airplane's acceleration rate to the V1 speed, particularly for critical length runways, and for runway surface conditions that may impede acceleration [Recommendation A-71-003].

On 2 February 1973, the NTSB further evaluated the recommendation and decided that it had been superseded by recommendations issued on 3 January 1972 relating to an accident during takeoff at San Francisco in 1971 (see below).

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<sup>1</sup> National Transportation Safety Board, 1972. *Aircraft Accident Report, Capitol International Airways, Inc., DC-8-63F, N4909C, Anchorage, Alaska, November 27, 1970* (Report No. NTSB-AAR-72-12).

### ***Boeing 747: July 1971<sup>2</sup>***

Location: San Francisco, US

On 30 July 1971 a Boeing 747-121, registered N747PA, with 19 crew and 199 passengers, collided with the Approach Light System (ALS) structure while taking off from runway 01R at San Francisco International Airport, California. The flight crew continued the takeoff and, after an in-flight inspection for damage, dumped fuel and returned for a landing at San Francisco. The aircraft had been dispatched for a departure from a closed runway and, upon changing to an open runway, the crew did not recompute the proper reference speeds for takeoff under the existing conditions. Two passengers were injured during the impact with the ALS and eight others sustained serious back injuries during the evacuation after the landing.

On 3 January 1972, the NTSB issued five recommendations to the FAA during the investigation into this accident including the following two recommendations relating to flight crew awareness of take-off performance:

3. require the installation of runway distance markers at all civil airports where air carrier aircraft are authorized to operate [Recommendation A-72-003].
4. require the use of takeoff procedures which will provide the flight crew with time and distance reference to associate with acceleration to  $v_1$  speed [Recommendation A-72-004].

The NTSB closed both recommendations on 16 September 1977 with the FAA response to recommendation No 3 being notated 'unacceptable action'.

### ***McDonnell Douglas DC-10: September 1980<sup>3</sup>***

Location: London Heathrow, United Kingdom (UK)

On 16 September 1980 a McDonnell Douglas DC-10-30, N83NA, with 17 crew and 220 passengers, sustained a tyre burst during the take-off run on runway 28R at London Heathrow Airport. The tyre burst was observed by the occupants of a runway clearance vehicle parked to one side of the runway, who transmitted the information to the control tower. This message was overheard by the aircraft commander who, as a result, rejected the takeoff at 168 kts, which was 8 kts above the calculated  $V_1$  speed of 160 kts.

The crew brought the aircraft to a stop about 110 m before the end of the runway. A successful evacuation was carried out using the escape slides on the left side, although one passenger suffered a broken leg. Two localised fires, which had developed in the centre and right wheel bogies, were extinguished by the Airport Fire Service.

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<sup>2</sup> National Transportation Safety Board, 1972. *Aircraft Accident Report, Pan American World Airways, Inc., Boeing 747, N747PA, San Francisco, California, July 30, 1971* (Report No. NTSB-AAR-72-17).

<sup>3</sup> Accidents Investigation Branch, Department of Trade, 1982. *Report on the Accident to McDonnell Douglas DC10-30 N83NA at London Heathrow Airport, on 16 September 1980* (Aircraft Accident Report No. 2/82).

The then UK Accidents Investigation Branch (AIB) issued the following recommendation in the investigation report dated 12 July 1982:

It is recommended that:

Development of a 'take-off performance monitor', with a cockpit display, be undertaken as a matter of urgency [Recommendation 4.15].

The UK Civil Aviation Authority responses to AAIB recommendation received up to 31 December 1989 were published in Civil Aviation Publication (CAP) 593 *Air Accidents Investigation Branch (AAIB) Recommendations: Progress Report 1990*. The progress report stated in relation to the above recommendation:

A reliable 'take-off performance monitor' in the cockpit would undoubtedly ease the pilots task during the ground run and the CAA would welcome the introduction of such an instrument. Efforts to develop an acceptable monitor have been underway for a number of years but, unfortunately, it appears that it may take some time before one is produced.

### ***Boeing 737: January 1982<sup>4</sup>***

Location: Washington, US

On 13 January 1982 a Boeing 737-222, registered N62AF, with five crew and 74 passengers on board, impacted the 14th Street Bridge and descended into the Potomac River after a takeoff from runway 36 at Washington National Airport, Washington, D.C. The aircraft came to rest in the water beyond the western side of the bridge about 0.75 NM (1.4 km) from the departure end of runway 36. Four passengers and one crewmember survived the accident. Four people in vehicles on the bridge sustained fatal injuries.

The NTSB determined that the accident resulted from the flight crew's failure to use engine anti-ice during ground operation and takeoff, their decision to take off with snow/ice on the airfoil surfaces of the aircraft, and the captain's failure to reject the takeoff during the early stage when his attention was called to anomalous engine instrument readings.

While the NTSB did not issue any specific recommendations in relation to take-off performance monitoring, it reiterated Safety Recommendation A-72-003 (see above) regarding the installation of runway distance markers.

As a result of this accident and another accident ten days later at Boston (see below) a Joint Aviation/Industry Landing and Takeoff Performance Task Group was formed to examine the concept of a take-off performance monitoring system.

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<sup>4</sup> National Transportation Safety Board, 1982. *Aircraft Accident Report, Air Florida, Inc., Boeing 737-222, N62AF, Collision with 14<sup>th</sup> Street Bridge, near Washington National Airport, Washington, D.C., January 13, 1982* (Report No. NTSB-AAR-82-8).

## **McDonnell Douglas DC-10: January 1982<sup>5</sup>**

Location: Boston, US

On 23 January 1982 a McDonnell Douglas DC-10-30CF, registered N113WA, with 12 crew and 200 passengers on board, touched down 2,800 ft (853 m) beyond the displaced threshold of runway 15R at Boston-Logan International Airport. During the landing roll the aircraft veered to avoid the approach light pier at the departure end of the runway and slid into the shallow water of Boston Harbour. The nose section separated from the forward fuselage as the aircraft dropped from the shore embankment. The NTSB determined that the accident resulted from the minimal braking effectiveness on the ice-covered runway. Two passengers were not found and were presumed dead. The other people on board evacuated the aircraft safely but with some injuries.

On 23 December 1982, the NTSB issued 18 recommendations to the FAA as a result of the investigation into this accident including the following recommendation relating to flight crew awareness of take-off performance:

Convene an industry-government group which includes the National Aeronautics and Space Administration to define a program for the development of a reliable takeoff acceleration monitoring system [Recommendation A-82-169].<sup>6</sup>

The FAA requested the Society of Automotive Engineers (SAE) to form an ad hoc committee to establish the requirements for a take-off performance monitoring system. In October 1987 the Society released SAE Aerospace Standard AS 8044, *Takeoff Performance Monitor (TOPM) System, Airplane, Minimum Performance Standard for*, which established a standard for TOPM systems, including the technical requirements and sampling and methods of test or inspection.

The NTSB noted the release of the SAE standard and evaluated the FAA advice of 5 May 1987 regarding the SAE activities. The NTSB advised the FAA on 1 April 1988 that it was closing recommendation A-82-169 with the FAA response being considered as 'Acceptable Action'.

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<sup>5</sup> National Transportation Safety Board, 1985. *Aircraft Accident Report, World Airways, Inc., Flight 30H, McDonnell Douglas DC-10-30CF, N113WA, Boston-Logan International Airport, Boston, Massachusetts, January 23, 1982* (Report No. NTSB/AAR-85/06). This report superseded an earlier report into the accident issued by the NTSB in 1982 (Report No. NTSB-AAR-82-15).

<sup>6</sup> Recommendation A-82-169 was also discussed in NTSB's report into the issue of aircraft performance in adverse airport conditions; refer National Transportation Safety Board, 1983. *Special Investigation Report, Large Airplane Operations on Contaminated Runways* (NTSB/SIR-83/02).

### **McDonnell Douglas MD-82: March 1994<sup>7</sup>**

Location: New York, US

On 2 March 1994, a McDonnell Douglas MD-82, registered N18835 with 6 crew and 110 passengers on board, sustained substantial damage following a rejected takeoff roll on runway 13 at LaGuardia Airport, Flushing, New York. The aircraft overran the runway and came to rest on a dyke. There were no fatalities or serious injuries but one flight crew member and 29 passengers sustained minor injuries during the evacuation of the aircraft. The NTSB determined that the accident resulted from the flight crew's failure to turn on the pitot/static heat system and their untimely response to anomalous airspeed indications with the consequent rejection of the takeoff at an actual speed of 5 kts above  $V_1$ .

The NTSB issued an investigation report into the accident on 14 March 1996. The report contained six recommendations to the FAA including the following three recommendations relating to the monitoring of take-off performance:

Require manufacturers of airplanes operated by air carriers to publish and distribute to operators specific elapsed times to target speeds (given normal acceleration, the times to given airspeeds) [Recommendation A-95-18].

Require that the elapsed times to target speeds be incorporated as part of the takeoff performance data available to air carrier flightcrews [Recommendation A-95-19].

Require that air carrier rejected takeoff training include elapsed time to target speed takeoff performance data [Recommendation A-95-20].

The FAA advised the NTSB on 28 February 1996 that it '... continues to believe that requiring a time/speed check during takeoff may result in unnecessary and potentially hazardous rejected takeoffs and increase flightcrew workload ... It [FAA] plans no further action on these recommendations'.

The NTSB closed the three recommendations on 14 May 1996 with the FAA response to the recommendations being considered as 'unacceptable action'. The Board stated that it '... continues to believe that until a takeoff performance system is developed, the use of time/speed checks would add an additional level of safety to takeoff performance without adding additional monitoring burdens to flightcrews'.

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<sup>7</sup> National Transportation Safety Board, 1995. *Aircraft Accident Report, Runway Overrun Following Rejected Takeoff, Continental Airlines Flight 795, McDonnell Douglas MD-82, N18835, LaGuardia Airport, Flushing, New York, March 2, 1994* (Report No. NTSB/AAR-95/01).

### **Boeing 747: October 2004<sup>8</sup>**

Location: Halifax, Canada

On 14 October 2004, a Boeing 747-244SF, registered 9G-MKJ, attempted to take off from runway 24 at the Halifax International Airport. The aircraft overshot the end of the runway for a distance of 825 ft (251 m), became airborne for 325 ft, then struck an earth mound. The aircraft's tail section broke away from the fuselage, and the aircraft remained in the air for another 1,200 ft before it struck terrain and burst into flames. The aircraft was destroyed by impact forces and a severe post-crash fire. All seven crew members were fatally injured.

The Transportation Safety Board of Canada (TSB) found that the accident resulted from a flight crew member not recognising that the laptop computer used to calculate the take-off performance data contained an incorrect aircraft weight from the previous flight. This incorrect weight was used to calculate performance data for the takeoff from Halifax, which resulted in incorrect take-off speeds and thrust settings being generated by the laptop computer. The crew then used the incorrect speeds and thrust settings which were too low to enable the aircraft to take off safely for the actual weight of the aircraft.

The Canadian TSB issued the following recommendation in the investigation report released on 29 June 2006:

Therefore, the Board recommends that:

The Department of Transport, in conjunction with the International Civil Aviation Organization, the Federal Aviation Administration, the European Aviation Safety Agency, and other regulatory organizations, establish a requirement for transport category aircraft to be equipped with a take-off performance monitoring system that would provide flight crews with an accurate and timely indication of inadequate take-off performance [Recommendation A06-07].

In 2007 the Canadian regulator, Transport Canada, formed a project team to examine the issue of a take-off performance monitoring system (TOPMS). In February 2009 Transport Canada tasked the National Research Council (NRC) of Canada to conduct a study into the background, technology, issues and certificatability associated with TOPMS.

The NRC released a report on the technology status of TOPMS in April 2009.<sup>9</sup> The report contained a proposal for a flight research and evaluation project to be conducted in the Council's Dassault Falcon 20 aircraft to ascertain the certificatability of current TOPM technology. This research and evaluation project did not proceed due to lack of funding and no further progress has been made regarding the TOPMS issue at the time of publishing this investigation report.

On 9 March 2011 the TSB noted that:

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<sup>8</sup> Transportation Safety Board of Canada, 2006. *Aviation Investigation Report, Reduced Power at Take-off and Collision with Terrain, MK Airlines Limited, Boeing 747-244SF, 9G-MKJ, Halifax International Airport, Nova Scotia, 14 October 2004* (Report No. A04H0004).

<sup>9</sup> Brown, A. P., and Abbasi, H., 2009. *Takeoff performance monitoring systems, technology, certificatability and operability status*, Flight Research Laboratory, Institute for Aerospace Research National Research Council, Canada.

The Board is concerned that TC [Transport Canada] has ended its research into TOPM technology. While the Board understands the complexity associated with such an undertaking, the fact that similar occurrences happen on a regular basis means that a mitigation strategy has to be developed. Because this is a global issue, the Board strongly encourages TC to continue its leadership in TOPM research but to also approach other agencies that could contribute resources.

However, at this date, the TC has stopped all work on TPMS [take-off performance monitoring system] technology and will only revisit this issue when a certifiable product is developed. This action plan will not substantially reduce or eliminate the safety deficiency.

Therefore, the Board assesses TC's response as **Unsatisfactory**

### ***Airbus A330: October 2008.***<sup>10</sup>

Location: Montego Bay, Jamaica

On 28 October 2008, an Airbus A330-243, registered G-OJMC, with 13 crew and 318 passengers, was taking off from runway 07 at Montego Bay/Sangster International Airport, Jamaica. Following the first officer's call to 'rotate', the captain pulled back on the sidestick and pitched the aircraft to about 10° nose up but the aircraft did not become airborne as expected. The captain then selected TO/GA power and the aircraft became airborne, climbed away safely, and the flight continued to the scheduled destination.

The UK AAIB investigation into the incident found that incorrect speeds were used for the takeoff due to an error in the take-off performance calculations. While the exact source of the error could not be determined, the investigation found deficiencies in the operator's procedures for calculating performance using their computerised performance tool.

The AAIB report into the incident, released in November 2009, stated that:

A system which actively monitors takeoff performance can add an additional safety net, independent of data input by flight crews. However, despite being identified as having a positive impact, little or no progress has been made in the development of takeoff performance monitoring systems in recent years. Such a system would require a high level of maturity before being introduced to avoid unnecessary and potentially unsafe crew actions.

As a consequence, the following recommendations are made:

Safety Recommendation 2009-080

It is recommended that the European Aviation Safety Agency develop a specification for an aircraft takeoff performance monitoring system which provides a timely alert to flight crews when achieved takeoff performance is inadequate for given aircraft configurations and airfield conditions.

Safety Recommendation 2009-081

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<sup>10</sup> Air Accidents Investigation Branch (AAIB), Department for Transport, 2009. *AAIB Bulletin Report on serious incident to Airbus A330-243, G-OJMC at Sangster International Airport, Montego Bay, Jamaica on 28 October 2008* (AAIB Bulletin No. 11/2009).

It is recommended that the European Aviation Safety Agency establish a requirement for transport category aircraft to be equipped with a takeoff performance monitoring system which provides a timely alert to flight crews when achieved takeoff performance is inadequate for given aircraft configurations and airfield conditions.

On 7 July and 27 September 2011, the European Aviation Safety Agency (EASA) responded to the above recommendations by advising the AAIB that the Agency considered the feasibility of a take-off performance monitoring system had not been demonstrated and that the Agency did not intend to establish a certification specification 'at this time'. The Agency also advised that the issue:

...has been proposed to be added to the European Organization for Civil Aviation Equipment (EUROCAE) Technical Work Programme. It is expected that a working group of experts will review the state of the art on the feasibility of such system. If it appears that technology is available, then the working group would propose a standard.

### ***Airbus A340: December 2009***<sup>11</sup>

Location: London Heathrow, UK

On 12 December 2009, an Airbus A340-642, registered G-VYOU, with 16 crew and 282 passengers, was taking off from London Heathrow Airport, UK. During the take-off roll the handling pilot '... noticed that the acceleration was slightly lower than it should have been but did not consider it particularly abnormal'. The aircraft was also slow to rotate and the initial climb performance was degraded with a low rate of climb at between 500 and 600 ft/min.

The UK AAIB investigation into the incident found that:

During pre-flight preparations, the estimated landing weight was used to calculate takeoff performance rather than the takeoff weight. The error was not detected and the aircraft took off using values for VR and V2 that were significantly lower than those required for the actual takeoff weight.

The AAIB investigation report referred to the two recommendations regarding take-off performance monitoring systems that were issued following the G-OJMC incident at Montego Bay in 2008. The AAIB stated that:

At the time of writing [June 2010], the AAIB had not received a detailed response from the EASA [European Aviation Safety Agency] regarding the recommendations but their nature is such that it will probably be a considerable time before a solution is operational. In the meantime, the Green Dot gross error check should provide a way to highlight that an error has been made in time for it to be investigated before departure.

As noted in the previous sub-section, in 2011 the AAIB received responses from EASA regarding the G-OJMC investigation recommendations.

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<sup>11</sup> Air Accidents Investigation Branch (AAIB), Department for Transport, 2010. *AAIB Bulletin Report on serious incident to Airbus A340-642, G-VYOU at London Heathrow Airport, on 12 December 2009* (AAIB Bulletin No. 7/2010).

### F.3 Take-off performance monitoring systems

The concept of onboard take-off performance monitoring systems (TOPMS) has been proposed since the 1950s.<sup>12</sup> and the system has been the subject of over 30 US patents during the period from 1956 to 2007.

Several organisations, including the US National Aeronautics and Space Administration,<sup>13</sup> Cranfield University in the UK,<sup>14</sup> the Dutch National Aerospace Laboratory (NLR), the University of Saskatchewan, Canada<sup>15</sup> and Risø National Laboratory, Denmark<sup>16</sup> have conducted research into TOPMS including the development and testing of prototypes. At the time of publication of this investigation report, there was no commercially available system for use in civil transport aircraft.

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<sup>12</sup> Morris, G. J., and Lina, L. J., 1954. *Description and preliminary flight investigation of an instrument for detecting subnormal acceleration during take-off*, National Advisory Committee for Aeronautics, Technical Note 3252, Washington, D.C.

<sup>13</sup> Middleton, D. B., Srivatsan, R., and Person, L. H., 1992. *Simulator Evaluation of Displays for a Revised Takeoff Performance Monitoring System*, National Aeronautics and Space Administration, Technical Paper 3270, Washington, D.C.

<sup>14</sup> Zammit-Mangion, D., and Eshelby, M., 2008. Design, Integration, and Preliminary Assessment of a Takeoff Monitor Display, *Journal of Aircraft* Vol. 45, No. 2, 371-380.

<sup>15</sup> Brown, A. P., and Abbasi, H., 2009. *Takeoff performance monitoring systems, technology, certificability and operability status*, Flight Research Laboratory, Institute for Aerospace Research National Research Council, Canada.

<sup>16</sup> Bove, T., and Andersen, H. B., 2002. The effect of an advisory system on pilots' go/no-go decision during take-off, *Reliability Engineering and System Safety* 75, 179-191.



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## APPENDIX G : PREVIOUS OPERATIONAL DATA FOR THE FLIGHT CREW

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Copies of the flight plans and loadsheets for all four flight crew for the 2 months prior to the accident were obtained from the operator. The following is a summary of the relevant performance parameters from those documents.

The flight plans provided were the 'Master' copies for the flights because the respective captain's copies were not archived by the operator.

### Legend for tables

Date	The date the flight was commenced.
Aircraft type	A330-243, A340-313K, or A340-541 aircraft.
AZFW	Aircraft zero fuel weight, in tonnes, from the loadsheet and rounded to nearest 100 kg (0.1 tonne).
ATOW	Actual take-off weight, in tonnes, from the loadsheet and rounded to nearest 100 kg (0.1 tonne).
FLTOW	Flex limiting take-off weight, in tonnes, from the flight plan.
Difference	FLTOW minus ATOW, in tonnes. Calculated by the investigation.
Flex Temp	Flexible take-off temperature, in °C, from the flight plan.
V <sub>1</sub>	V <sub>1</sub> , in kts, from the flight plan.
V <sub>R</sub>	V <sub>R</sub> , in kts, from the flight plan.
V <sub>2</sub>	V <sub>2</sub> , in kts, from the flight plan.
Config	Flap configuration from the flight plan.
Green dot speed	The green dot speed, in kts, that was identified on the flight plan and/or the loadsheet. Note that there was no consistency in how or where this was marked.



## G.1 Captain

Date	Aircraft Type	AZFW (tonnes)	ATOW (tonnes)	FLTOW (tonnes)	Difference (tonnes)	Flex Temp (deg C)	V <sub>1</sub> (kts)	V <sub>R</sub> (kts)	V <sub>2</sub> (kts)	Config	Flt Plan	Green Dot Speed (kts)
21-Jan-09	A340-500	216.2	335.7	335.8	0.1	54	153	161	170	3	254	
22-Jan-09	A340-500	209.2	243.9	244.0	0.1	74	142	142	149	3	218	
24-Jan-09	A340-500	222.8	257.4	258.0	0.6	75	144	144	152	3	223	223
25-Jan-09	A340-500	219.0	350.5	351.5	1.0	48	151	162	173	3	260	
01-Feb-09	A340-300	153.3	211.7	212.4	0.7	55	134	139	146	1+F	242	
04-Feb-09	A340-300	167.2	255.6	256.2	0.6	39	142	150	157	2		
11-Feb-09	A340-300	158.8	225.6	226.5	0.9	54	150	153	158	1+F		251
12-Feb-09	A340-300	166.3	219.3	220.0	0.7	53	138	144	155	1+F		
19-Feb-09	A340-500	211.5	333.7	334.2	0.5	52	150	156	167	3	254	
21-Feb-09	A340-500	225.7	360.0	360.4	0.4	45	151	162	173	3	264	
25-Feb-09	A340-300	167.6	215.5	216.0	0.5	54	134	140	147	1+F	245	244
27-Feb-09	A340-300	175.8	219.1	(1)								
03-Mar-09	A340-500	202.4	314.3	315.0	0.7	60	149	156	165	2		
05-Mar-09	A340-500	227.8	361.1	(1)								
10-Mar-09	A340-300	163.6	222.7	223.0	0.3	50	136	141	148	1+F	249	
12-Mar-09	A340-300	159.7	225.1	225.5	0.4	36	144	154	160	1+F	250	
18-Mar-09	A340-500	202.5	317.5	318.6	1.1	52	148	152	163	3		
20-Mar-09	A340-500	226.6	361.8	262.9	-98.9	74	143	145	157	1+F		

(1) Flight plan not supplied, archived copy not located.

## G.2 First Officer

Date	Aircraft Type	AZFW (tonnes)	ATOW (tonnes)	FLTOW (tonnes)	Difference (tonnes)	Flex Temp (deg C)	V <sub>1</sub> (kts)	V <sub>R</sub> (kts)	V <sub>2</sub> (kts)	Config	Green Dot Speed (kts)	
											Flt Plan	Loadsheet
19-Jan-09	A330-200	152.4	197.0	198.0	1.0	63	148	148	154	1+F		
20-Jan-09	A330-200	136.1	169.0	169.0	0.0	60	118	127	133	1+F		
26-Jan-09	A330-200	151.3	189.5	190.2	0.7	63	127	137	143	2	221	221
27-Jan-09	A330-200	139.9	170.6	171.4	0.8	62	115	120	127	2	210	209
30-Jan-09	A340-300	170.3	238.9	240.0	1.1	49	152	155	161	1+F		
31-Jan-09	A340-300	170.9	220.8	221.5	0.7	54	144	151	157	1+F		
09-Feb-09	A330-200	152.3	190.1	190.2	0.1	63	127	138	143	2		
10-Feb-09	A330-200	141.6	169.0	169.1	0.1	62	113	115	122	3		
20-Feb-09	A340-500	218.5	346.8	348.6	1.8	50	157	164	172	3	259	
22-Feb-09	A340-500	195.4	313.0	314.0	1.0	57	148	153	162	3		
03-Mar-09	A340-500	212.2	269.3	270.4	1.1	74	144	146	155	1+F		
04-Mar-09	A340-500	206.0	251.7	252.8	1.1	68	141	143	152	1+F		
09-Mar-09	A340-500	202.8	322.3	323.7	1.4	58	155	161	169	3		
11-Mar-09	A340-500	224.3	356.9	357.4	0.5	45	150	160	172	3		
15-Mar-09	A330-200	151.2	180.8	(1)								
15-Mar-09	A330-200	146.6	165.2	(1)								
18-Mar-09	A340-500	202.5	317.5	318.6	1.1	52	148	152	163	3		
20-Mar-09	A340-500	226.6	361.8	262.9	-98.9	74	143	145	157	1+F		

(1) Flight plan not supplied, archived copy not located.

### G.3 Augmenting Captain

Date	Aircraft Type	AZFW (tonnes)	ATOW (tonnes)	FLTOW (tonnes)	Difference (tonnes)	Flex Temp (deg C)	V <sub>1</sub> (kts)	V <sub>R</sub> (kts)	V <sub>2</sub> (kts)	Green Dot Speed (kts)	
										Flt Plan	Loadsheet
19-Jan-09	A330-200	141.6	185.3	186.0	0.7	63	123	134	140	1+F	218
20-Jan-09	A330-200	151.0	177.3	178.0	0.7	59	120	130	137	1+F	213
21-Jan-09	A330-200	149.4	163.8	163.9	0.1	63	113	116	124	2	205
22-Jan-09	A330-200	141.8	151.2	152.0	0.8	63	111	111	120	2	198
23-Jan-09	A330-200	160.9	202.1	202.7	0.6	62	154	154	160	1+F	228
23-Jan-09	A330-200	149.5	170.0	170.8	0.8	63	118	126	134	1+F	209
26-Jan-09	A330-200	155.8	172.2	172.8	0.6	63	116	120	127	2	
27-Jan-09	A330-200	144.9	158.4	159.0	0.6	62	112	113	122	2	202
30-Jan-09	A330-200	160.1	179.8	180.0	0.2	63	121	131	137	1+F	215
31-Jan-09	A330-200	131.7	147.0	148.0	1.0	63	111	111	120	2	196
03-Feb-09	A340-300	157.0	226.4	226.5	0.1	53	144	151	156	1+F	251
04-Feb-09	A340-300	142.4	156.2	156.5	0.3	54	129	130	139	2	209
04-Feb-09	A340-300	146.0	194.6	195.0	0.4	54	130	131	138	3	232
05-Feb-09	A340-300	173.7	230.0	230.5	0.5	48	137	143	150	1+F	253
10-Feb-09	A330-200	167.9	200.3	201.0	0.7	62	151	151	157	1+F	227
10-Feb-09	A330-200	165.1	194.8	195.3	0.5	55	139	139	145	2	224
13-Feb-09	A330-200	151.5	187.9	188.0	0.1	63	133	135	141	2	220
13-Feb-09	A330-200	152.7	174.4	175.0	0.6	62	116	121	128	2	212
16-Feb-09	A330-200	155.6	195.4	196.1	0.7	58	137	137	143	2	224
16-Feb-09	A330-200	144.3	166.7	167.2	0.5	61	117	124	132	1+F	207
19-Feb-09	A340-300	168.0	239.1	240.2	1.1	47	148	153	159	1+F	258
20-Feb-09	A330-200	138.9	151.9	153.0	1.1	62	114	117	127	1+F	198
20-Feb-09	A330-200	140.3	182.8	184.4	1.6	62	121	130	136	2	217
21-Feb-09	A340-300	161.3	213.9	214.0	0.1	54	134	140	147	1+F	243
24-Feb-09	A330-200	146.2	173.6	173.6	0.0	62	116	121	127	2	211

Date	Aircraft Type	AZFW (tonnes)	ATOW (tonnes)	FLTOW (tonnes)	Difference (tonnes)	Flex Temp (deg C)	V <sub>1</sub> (kts)	V <sub>R</sub> (kts)	V <sub>2</sub> (kts)	Config	Flt Plan	Green Dot Speed (kts) Loadsheet
25-Feb-09	A330-200	149.3	173.5	175.0	1.5	62	116	121	128	2	211	211
26-Feb-09	A330-200	161.6	178.4	179.5	1.1	62	118	125	131	2	214	214
27-Feb-09	A330-200	142.2	157.8	158.4	0.6	62	112	113	122	2	202	
01-Mar-09	A330-200	158.7	201.0	201.8	0.8	60	151	154	159	2		228
01-Mar-09	A330-200	161.3	189.1	189.8	0.7	61	138	138	144	2		220
09-Mar-09	A340-500	197.2	295.6	296.3	0.7	66	149	155	164	1+F		238
10-Mar-09	A340-500	216.4	312.6	313.0	0.4	50	147	151	161	3		
16-Mar-09	A340-500	202.6	316.0	316.5	0.5	62	154	161	169	1+F		
17-Mar-09	A340-500	216.7	253.0	253.2	0.2	74	142	142	150	3		
19-Mar-09	A340-500	224.3	266.0	266.8	0.8	74	145	147	155	1+F		
20-Mar-09	A340-500	226.6	361.8	262.9	-98.9	74	143	145	157	1+F		

## G.4 Augmenting First Officer

Date	Aircraft Type	AZFW (tonnes)	ATOW (tonnes)	FLOW (tonnes)	Difference (tonnes)	Flex Temp (deg C)	V <sub>1</sub> (kts)	V <sub>R</sub> (kts)	V <sub>2</sub> (kts)	Config	Flt Plan	Green Dot Speed (kts) Loadsheet
18-Jan-09	A330-200	160.3	216.2	216.5	0.3	55	159	159	165	1+F		
19-Jan-09	A330-200	142.3	185.4									
24-Jan-09	A330-200	164.8	180.5	181.0	0.5	63	121	131	138	1+F		
24-Jan-09	A330-200	138.8	150.8	151.4	0.6	62	111	111	120	2		
09-Feb-09	A330-200	156.1	178.4	178.9	0.5	63	120	130	137	1+F		
09-Feb-09	A330-200	149.7	164.7	165.5	0.8	56	117	125	132	1+F		
11-Feb-09	A330-200	152.6	177.0	177.5	0.5	62	116	122	129	2		
11-Feb-09	A330-200	156.0	173.1	174.6	1.5	48	132	137	142	1+F		212
13-Feb-09	A330-200	147.0	187.1	187.5	0.4	62	123	133	139	2		
14-Feb-09	A330-200	154.3	191.2	192.0	0.8	59	155	156	161	1+F		
18-Feb-09	A330-200	150.3	192.2	192.3	0.1	62	130	139	145	2		
19-Feb-09	A330-200	152.6	189.0	189.0	0.0	57	145	145	151	1+F		
21-Feb-09	A330-200	151.6	192.0	193.0	1.0	62	137	141	147	2		
22-Feb-09	A330-200	155.0	191.3	192.0	0.7	58	154	159	159	1+F		
27-Feb-09	A330-200	148.1	191.5	192.0	0.5	62	130	140	145	2		
28-Feb-09	A330-200	148.7	183.7	184.1	0.4	63	122	132	139	1+F		
03-Mar-09	A330-200	154.3	182.0	182.7	0.7	63	123	128	134	2		
03-Mar-09	A330-200	141.4	160.9	162.7	1.8	58	116	123	131	1+F		
16-Mar-09	A340-500	202.6	316.0	316.5	0.5	62	154	161	169	1+F		
17-Mar-09	A340-500	216.7	253.0	253.2	0.2	74	142	142	150	3		
19-Mar-09	A340-500	224.3	266.0	266.8	0.8	74	145	147	155	1+F		
20-Mar-09	A340-500	226.6	361.8	262.9	-98.9	74	143	145	157	1+F		



# APPENDIX H : OPERATIONAL FLIGHT DOCUMENTS

The following are copies of the first page of the 'Master' flight plan and the Aircraft Communications Addressing and Reporting System (ACARS) loadsheet from the occurrence flight. The annotations on the documents were made by the flight crew during the flight.

## H.1 'Master' flight plan

The flight plan contained information on the planned route. The take-off performance calculations were transcribed onto page '1' during the pre-departure preparation.

2  
MASTER

**UAE407 YMML-OMDB 20MAR09/11:25Z**

EK407 20MAR YMML/MEL-OMDB/DXB A340-500-ERG CAPT: Captain's name  
SIGNATURE: Captain's signature

ATC CLRNC: *8500 to 5000 1465*  
DEPRTE : YMML *(16)* DCT ME H345 BOR DCT AP DCT AKDAB DCT BUSAD DCT  
ISMOR DCT UGAVI DCT MELBO DCT SAPDA 1895 DUGOS N66T AKMIL N568  
EMURU P570 IPORA M762 BUBIN OMDB 30R

PLND FL: 320 SAPDA/360 UPROB/380 OPIRA/400 ✓  
ENROUTE RECLRNC:

OFF: *23/0/0* WX PROG 06/12/18/24 CTOT: ..... PARKING BAY: *P11*

	FUEL	TIME	CORR	ARR	0140	
TRIP OMDB	125689	1408	<i>125.3</i>	DEP	1125	<i>124.7 1236</i>
CONT <i>ADMINS</i>	2964	0020	.. ..	BT	1415	<i>111.7 1131</i>
ALTN <i>OMFJ</i>	3067	0021	.. ..	GND DIST		<i>0130 0104</i>
FRSV	3589	0030	.. ..	AIR DIST		<i>6413</i>
ADDNL	.....	.....	.....	CRZ DEG		<i>6679</i>
T/O FUEL	135309		<i>..9</i>	CID		<i>10</i>
TAXI	816	0017		CRZ		<i>BCON</i>
RAMP FUEL	136.2	1519	<i>136.8</i>	CRZ FL/TEMP	FL320/M45	
				TOC TROP	45377	

ADJUST  
ADJ RAMP FUEL .. .. .  
FUEL REMN .. .. .  
FUEL USED .. .. .

*136.2*  
*57.3*  
*Letisian* → *84.3*

AV TRK 307 CREW *18*  
AV W/C M017 PAX *257*  
AV ISA P08 TOT *275*

ZFW CHG PS 1000 BURN PS 493 / MS 1000 BURN MS 548  
FL BELOW -1- BURN PS 3310 / TIME 1402

NO TANKERING RECOMMENDED (P) EXTRA FUEL REASON: ATC *(WX)* MEL ALTN OTH

YMML ATIS: *U/*

DOW RANGE 176.6 *183.3* 184.3 ✓ DOI RANGE 113.0 *120.5* 124.0

EZFW 227400 MZFW 230000 AZFW *226.6*  
ETOW 362709 MTOW ~~372000~~  
ELWT 237020 MLWT ~~243000~~ ✓ RTOW  
RLWT

RWY GWCG FLEX FLTOW V1 VR V2 ACC CONF EOP  
16... *16.9 74.362.9 143.145.184.121F* ...STD.....  
16... *44.362.9 152.163.173.190.6.3* ...STD..... ← DONE AIRBORNE BY FO

226.6

Page 1 of 52

## H.2 Loadsheet

The loadsheet was sent to the aircraft via the ACARS and was printed on the aircraft printer by the flight crew. The captain annotated the loadsheet with the time that he received it.

7

1054 2

ATSU . A6-ERG UAE407 E00309 10:53:31  
COCKPIT PRINTER MESSAGE - LABEL C1  
.DXBEGEK 201053  
AGM  
AN A6-ERG/PI EK407/MA. 453A  
- LOADSHEET  
FINAL1 EK0407/20 MELDXB A6ERG 20MAR09  
CREW 4/14 ✓ PAX 11/42/202 TTL 257  
ZFW 226549 ✓ MAX 230000L  
TOF 135300  
TOW 361849 ✓ MAX 372000  
TIF 125300  
LAW 236549 ✓ MAX 243000  
BALANCE AND SEATING  
DOW 183235 ✓ DOI 120.5 ✓  
LIZFW 114.7 MACZFW 28.7 ✓  
LITOW 113.9 MACTOW 27.1 ✓  
STAB TO 3.5 NOSE UP ✓  
A11. B42. C75. D127. PW 19759  
1/6700 2/8015 3/5975 4/2865 T23555  
UNDERLOAD 3451  
LMC

DEST	SPEC	PLUS/MINUS	WT/INDEX
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SI  
\*\*\*NOTOC REQUIRED: YES\*\* - CHECK TRANSIT NOTOC  
CHKD  
APVD  
TRANSIT NOTOC/NO  
WT REPORT NBR...12A  
LIRF NBR...01  
ENDEK0407

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## APPENDIX I : SOURCES AND SUBMISSIONS

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### Sources of Information

The main sources of information during the investigation included the:

- flight crew and cabin of the aircraft
- aircraft operator
- aircraft manufacturer
- flight data, cockpit voice and digital aircraft condition monitoring system recorders
- airport operator.

### Submissions

Under Part 4, Division 2 (Investigation Reports), Section 26 of the *Transport Safety Investigation Act 2003* (the Act), the Australian Transport Safety Bureau (ATSB) may provide a draft report, on a confidential basis, to any person whom the ATSB considers appropriate. Section 26 (1) (a) of the Act allows a person receiving a draft report to make submissions to the ATSB about the draft report.

A draft of this report was provided to the flight crew, the United Arab Emirates General Civil Aviation Authority (GCAA), the aircraft operator, the French Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), the aircraft manufacturer, the European Aviation Safety Agency (EASA), the United States (US) National Transportation Safety Board, the US Federal Aviation Administration, the Civil Aviation Safety Authority and Airservices Australia (Airservices). Submissions were received from the flight crew, the operator, the GCAA, EASA, the BEA, the aircraft manufacturer and Airservices. The submissions were reviewed and, where considered appropriate, the text of the report was amended accordingly.

Tailstrike and runway overrun - Melbourne Airport, Victoria, 20 March 2009  
- A6-ERG Airbus A340-541