Flight Crew Computer Errors (FMS, EFB) Case Studies

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NOTE

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Introduction

The purpose of this document is to provide examples of FMS related accidents for group discussion. These case studies are designed to be used in training sessions, where pilots can review the accidents and identify missed opportunities. Every accident has multiple potential opportunities, and in some cases the elimination of one or more of the factors may have prevented the event from becoming an accident. This document identifies five different errors sources:

1) Database
    - Typing errors
    - Incorrect way point / fix position calculation
    - Incorrect source documentation
    - Non adherence to ICAO or ARINC 424 Specifications

2) Position update
    - Incorrect position DME station
    - Inadvertent update-station frequency change
    - Out of DME coverage flying
    - Entering DME coverage area
    - Update out of DME usable sector
    - VOR/DME update

3) FMC program and database stored data interaction
    - Complex procedures may interact with aircraft performance limitations
    - Aircraft performance overrules FMC commands
    - Unintended aircraft response
    - Automation 'surprises'

4) Pilot error
    - Human Factor issues
    - Pilot FMC interface
    - Lack of commonality between systems
    - Paper Chart versus Nav display
    - System handling complexity

5) ATC 'interference'
    - Last minute changes / re-programming
    - Forced change in level of automation

Future editions of this document will continue to expand the knowledge base and identify additional areas of risk or phases of flight where this risk might occur.

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1. Navigational Error

2. Take Off Performance Calculation and Entry Errors

Summary of Incidents

Case Study	Aircraft Type	Date	Location	Phase of Flight			Error Details			Consequence
				Take Off	Cruise	Approach	Error Category	Performance Parameter[1]	Device[2]	
1	B757-223	20 Dec 1995	Cali, Colombia			X	Select and Data Entry: Navigational Error		FMC	Collision with Terrain
2	B777-300	23 Dec 2006	North Atlantic		X		Incorrect Position Inserted: Navigational Error		FMC, ACARS and OFP (Documentation)	
3	B767-300ER	13 Dec 2008	Manchester, England	X			Data Entry	Take Off Weight	Laptop Computer	Tailstrike
4	B777-300ER	22 Mar 2007	Auckland, New Zealand	X			Data Entry	Take Off Weight	Take off data card	Tailstrike
5	A330-243	28 Oct 2008	Montego Bay, Jamaica	X			Unknown	Take Off Weight	Unknown	Reduced take off performance
6	A340-642	12 Dec 2009	London, England	X			Data Entry	Take Off Weight	Loadsheet and performance procedure being completed out of sequence.	The aircraft was slow to rotate and initial climb performance
7	B747-300	2 Jun 2007	Changai, Singapore	X			Data Entry	Take Off Weight	Documentation	Collision With Obstacle
8	B747-400	10 Dec 2006	Orly, France	X			Data Entry	Take Off Weight	Laptop	Tailstrike
9	B747-400	13 Oct 2004	Halifax, Canada	X			Calculation	Take Off Weight	Laptop	Collision With Terrain

[1]**Performance parameter:** Refers to the take-off performance parameter that was either erroneously used to calculate other performance parameters, erroneously entered into an aircraft system, or not updated or checked after a change in flight conditions.

[2]**Device:** Refers to the aircraft system that was being used, calculate or enter take-off performance parameters. Devices included aircraft documentation and charts, take-off data cards, laptop computers, electronic flight bag, and aircraft systems such as the aircraft communications addressing and reporting system (ACARS)

Navigational Errors

B757-223, Near Cali, Colombia,
20 December 1995

Case Study 1

Navigational Error

Navigational Error – Loss of Situational Awareness
Boeing 757-223, near to Cali, Colombia, 20 December 1995

The factual information for this accident was taken from the report by Aeronautica Civil of the Republic of Colombia, available at http://bit.ly/hUrncj. The following study constitutes observations on the incident in the light of this report and does not purport to be an independent assessment of the accident. It is provided for the purpose of reducing the likelihood of future incidents, and does not seek to apportion blame or liability.

The Accident

The Boeing 757 was operating a scheduled passenger service from Miami, USA to Cali, Colombia with 2 pilots, 6 cabin crew and 155 passengers, most of whom died in the accident.

After waiting for connecting passengers and other delays, the flight departed from Miami almost 2 hours late for the 3 hour flight to Cali, which otherwise proceeded normally until the arrival in to Cali. Cali Approach cleared the flight to Cali (airfield), to descend to an altitude of 15,000 feet on the local QNH and to report passing the ULQ VOR. Control was procedural due to the absence of approach radar. The Captain misunderstood the clearance as direct to Cali VOR to the South of the airfield and entered this in the Flight Management Computer (FMC), effectively deleting all intervening waypoints.

The pilots had planned for the ILS approach to runway 01 and this had been programmed into the FMC but as they tracked towards Cali VOR from the North the controller offered the ‘straight in’ VOR/DME approach to runway 19, which the crew accepted. The clearance was for the Rozo 1 arrival for the VOR/DME 19, with no additional altitude constraints beyond those published on the chart.

The Captain subsequently requested direct to the Rozo NDB (identifier ‘R’), on the approach to runway 19 and he misunderstood this to have been approved. The controller actually reiterated the clearance for the Rozo 1 arrival, with an instruction to report 21 miles on the DME and 5,000 feet (Cali airfield elevation is 3,162 feet). Shortly thereafter the aircraft turned approximately 90 degrees left of the cleared route and flew east for 1 minute before turning back to the right, in a continuous descent.

Passing approximately 9,000 feet in instrument meteorological conditions (IMC) the aircraft’s ground proximity warning system (GPWS) ‘terrain’ warning activated and in spite of efforts by the pilots to respond to the warning, the aircraft crashed into a mountainside.

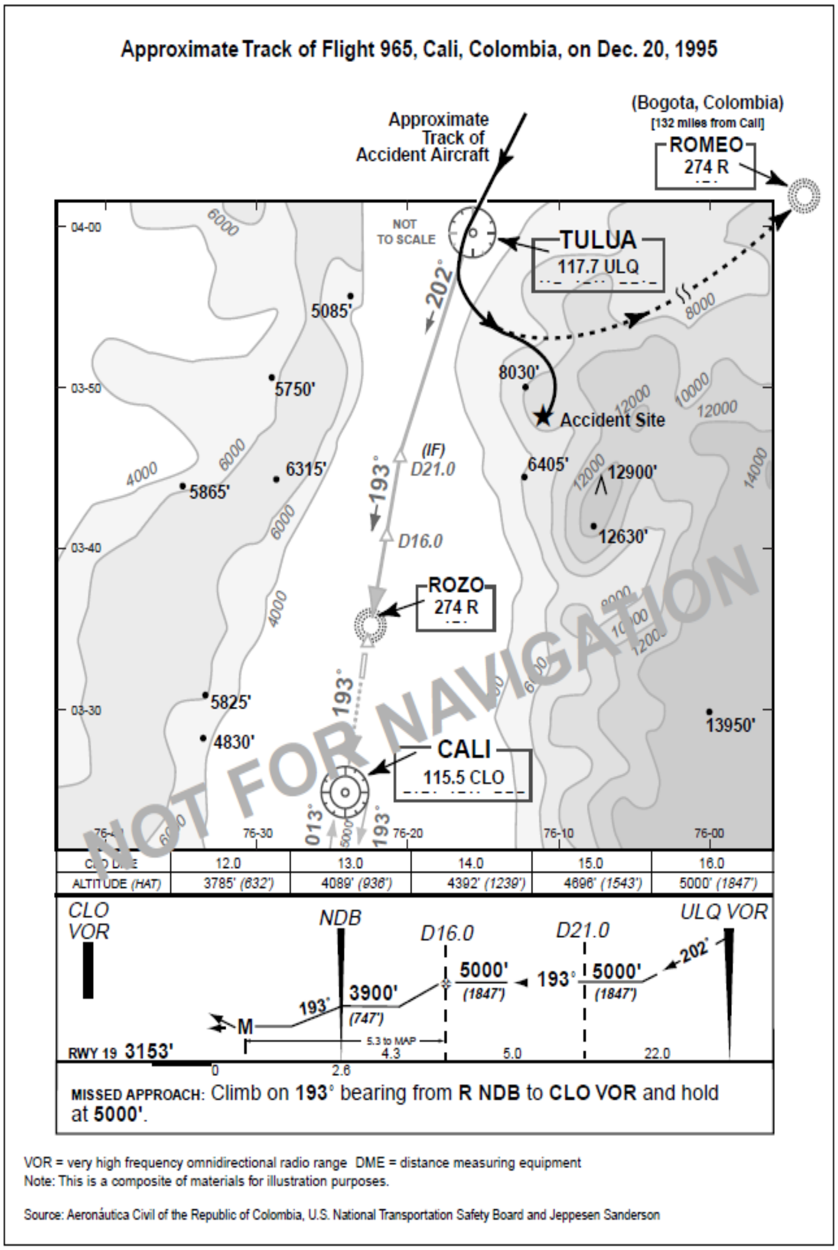
The Investigation

The investigation attributed the accident to a number of errors made by the pilots, beginning with their acceptance of the runway and approach change offered by ATC, which dramatically shortened the distance to touchdown and the time available to prepare for the approach. There was some evidence to suggest that the pilots attempted to locate the approach chart for runway 19 in the descent but tests on the FMC indicated that the approach was never changed from runway 01.

When the captain thought ATC had approved the request for direct to Rozo, the investigation concluded that he entered the identifier ‘R’ into the FMC to provide navigational guidance for the auto flight system. However, although this was the identifier for Rozo NDB, it was also the identifier for the Romeo NDB near Bogota to the East, and the FMC navigation aid protocols did not permit such closely located beacons to be selected by the same identifier. Entering ‘R’ would offer the user the Romeo NDB (due to the database hierarchy) but to access Rozo NDB it was necessary to enter ‘ROZO’.

Tests on the FMC indicated that it had been programmed to track direct to Romeo NDB and this is supported by the recorded turn to the East. After approximately one minute the pilots recognized that the aircraft navigation was incorrect and they turned back to the right towards Cali but continued to descend, apparently unaware of high terrain now between them and the Runway 19 approach course. The descent was expedited by use of the speedbrakes.

When the GWS ‘terrain’ warning activated the autopilot was disconnected and a large nose up input made on the controls but it was insufficient to avoid impact. The speedbrakes remained extended and it was not possible to determine whether the accident would have happened had they been retracted in the ‘escape’ maneuver.



This illustration is extracted from the Flight Safety Foundation-Flight Safety Digest-May-June 1998

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Technical	
ATC/navigation	
Environmental	
Human	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the accident:

Observations for Facilitators

Having suffered a delay out of Miami it would not be unusual for the crew to feel a desire to catch up what time they could during the flight. However, in this case they accepted an apparently time saving clearance which was entirely inappropriate. The accident stemmed directly from the decision to accept the approach to runway 19 without requesting to hold, which consequently reduced the distance to touchdown and allowed insufficient time for the pilots to prepare. The cockpit workload increased substantially, accompanied by a crucial loss of situational awareness.

Bearing in mind the high terrain and procedural ATC environment, the erroneous belief that they had been cleared first direct to Cali VOR and later direct to Rozo NDB (close to the landing threshold) but in both cases to report passing an intervening waypoint, made no sense and should have been questioned.

The Captain's failure to recognize that the FMC was not offering Rozo NDB in response to the selection of the 'R' identifier may be attributed to workload or to unfamiliarity with the system's operation. Inconsistent FMC programming characteristics (driven by technical limitations and/or the geographical distribution of navigational aids) have potential to confuse the user. The delay in recognizing the plainly anomalous aircraft navigation to the east was almost certainly a function of workload and lost situational awareness.

Once the pilots realized that they had not been navigating towards Rozo and were not on the published approach, it should have been clear to them that they were lost. In such a critical environment (no radar and high terrain) it would have been appropriate to climb immediately to the minimum safe altitude to provide terrain clearance, before setting course for a known navigational facility. To continue to descend in such circumstances was to invite disaster, and again indicative of excessive workload and poor decision making.

While it is not clear whether retracting the speedbrakes in the escape maneuver would have saved the aircraft, it can be assumed that it would have improved the aircraft climb performance.

Workshop participants should identify some or all of the following threats:

Technical - FMC system architecture; process for selection of Rozo NDB

ATC/Navigation

- Offer of 'straight in' approach
- Well-intentioned but not operationally feasible
- Existence of two NDBs with 'R' identifier
- Potential for confusion
- Lack of approach radar
- ATC situational awareness

Environmental

- IMC
- Lack of visual terrain cues
- High terrain
- Risk of ground collison

Human - Time pressure (perceived or actual); potential to induce bad decisions

And Errors:

- Workload management
- Desire to proceed direct without good situational awareness
- Decision to accept a clearance that was not operationally feasible
- Commencing approach without adequate preparation/briefing

- Acceptance of misunderstood ‘direct to’ clearances, inappropriate for flight conditions
- Selection of ‘direct to’ the incorrect NDB
- Delay recognizing the navigational error
- Continued descent with sever degradation in situational awareness

TEM Strategies:

Operator – for operations in high risk locations without surveillance radar it is essential for pilots to maintain situational awareness. One of the greatest threats to situational awareness is inappropriate prioritization when workload management is key to safety. Pilot training should help to build good habits that promote situational awareness and develop the use of appropriate tools for good task and workload management. The development and utilization of technologies like enhanced GPWS (EGPWS) and terrain displays will also aid in the management of both workload and situational awareness. Any inconsistent FMC programming characteristics, like the need to enter the navigation aid name rather than the identifier, should be adequately highlighted to pilots. Standard Operating Procedures, policies, and training should support the approach that if in doubt or uncertain of the aircraft’s position at any time, it is vital to climb to a safe altitude immediately prior to making any further navigational decisions.

ATC – high terrain and non-radar air traffic management are incompatible from the perspective of best practice in safety of flight. Air traffic service providers should endeavor to offer standards of service appropriate to the environment and its inherent threats.

Individual – time pressure, whether perceived or actual, can lead to poor decision making and pilots must develop Threat Error Management strategies that promote safe operations – accepting track shortening and/or runway changes may not be an appropriate decision, based on situational awareness and flight conditions. Pilots must also be able to recognize when the cockpit workload is reaching a level that threatens to erode their ability to safely and correctly manage the flight. When operating in a procedural ATC environment it is essential that all instructions are clearly understood, and queried if they are not. Acceptance of direct routing when close to high terrain should only be with careful consideration for the implications. Finally, whenever there is any doubt with regard to aircraft position it is vital that a safe altitude is achieved and maintained until situational awareness is regained and questions about the state of the aircraft are resolved.

B777-300, Potential Gross Navigation Error, North Atlantic
23 December 2006

Case Study 2

Potential Gross Navigation Error

Incorrect Position Inserted
Boeing 777-300, North Atlantic, 23 December 2006

The following study constitutes observations in the light of reports from the pilots and from UK NATS and does not purport to be an independent assessment of the incident. It is provided for the purpose of reducing the likelihood of future incidents, and does not seek to apportion blame or liability.

The Incident

The Boeing 777 was operating a scheduled ultra-long haul service from the Middle East to the United States, with an “augmented” crew of four pilots.

Prior to departure the operating crew uplinked the flight planned route to the flight management computer (FMC), and cross-checked the waypoints against the operational flight plan (OFP). They observed an unusual ‘dog-leg’ in the random route over the North Atlantic, but found it to be in accordance with the filed flight plan. The relevant section of the route was:

PIKIL (oceanic gateway) - 55°00’N/20°00’W - 57°00N/30°00W

Several hours into the flight, with the augmenting pilots in control, a request was sent by ACARS (Aircraft Communication Addressing and Reporting System) for the oceanic clearance, and this was delivered by the ACARS printer shortly thereafter. The pilots checked the clearance against the OFP and observed no difference – the uplinked route in the FMC remained unchanged.

As the flight passed position PIKIL the controller noticed a ‘route conformance alert’ indicating that the next point in the aircraft’s route, automatically communicated from the FMC via datalink, did not conform to the earlier clearance. To confirm this, the controller sent a datalink request to the aircraft to confirm the co-ordinates of their waypoint at 20°00W, and received the response 55°00’N/20°00’W. Immediately thereafter the controller received a datalink request from the aircraft to proceed direct to 57°00’N/30°00’W, and this was approved.

The Investigation

The investigation determined that the augmenting crew had failed to observe that the clearance received by ACARS included the note ‘ATC/ROUTE AMENDMENT’. The clearance differed from the OFP (and hence the FMC) route at 20°W and they should have amended the FMC route to:

PIKIL - 56°00’N/20°00’W - 57°00’N/30°00’W

This uncorrected discrepancy caused the route conformance alert at waypoint PIKIL. However, the controller’s query regarding the coordinates at 20°W did not alert the pilots to the incorrect waypoint and their request to fly direct to the next waypoint at 30°W was motivated by a desire to avoid flying the ‘dog-leg’ observed in the flight planned route. ATC plotted the aircraft approximately 23 nautical miles south of the cleared route at the time it turned onto the direct track to 57°00’N/30°00W and therefore a gross navigation error (defined as 25 nautical miles or more) was avoided.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Meteorological	
Procedural	
Human	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the accident:

Observations for Facilitators

North Atlantic Minimum Navigation Performance Specification (MNPS) Operations Manual 2005 edition, published by the ICAO European and North Atlantic office reminds operators to 'fly the clearance not the flight plan' and the ACARS clearance included a note to highlight that a change had been made. However, the difference was only a single digit at 20°W (56 instead of 55) and once overlooked it would have been a difficult error for the pilots to realize. The automated route conformance alert was designed to detect such discrepancies and functioned correctly.

It was not clear from the reports why the controller did not notify the pilots of their error at the time. Had he done so they may have elected to perform a further cross-check of the FMC route against the clearance to identify any further errors – as it was, there were none but the controller could not have known this.

The existence of an automated route conformance check in the ATC system suggests that the manual (human) cross-check used on board the aircraft may be inadequate and an automated system could be more appropriate.

Workshop participants should identify some or all of the following threats:

Organizational – heavy crew; the augmenting pilots may not have been as closely involved at the planning stage

Meteorological – not a factor

Procedural – manual clearance cross-check; easy to overlook a single digit change

Human – confirmation bias; adapting reality to meet expectations

And Errors:

- Failure to observe the message ATC/ROUTE AMENDMENT in the clearance
- Overlooking the single digit difference between the clearance and the flight plan
- Controller omitting to inform the pilots of their error

TEM Strategies:

Operators – there appears to be an opportunity for operators to work with manufacturers to develop route conformance software to inform pilots if the route entered into the FMC is aligned with the current clearance, as is done already for controllers. In the interim, clearances issued with amendments to the original flight plan should have the changes highlighted by a different font or style to draw pilots' attention to the specific change.

Pilots – it is very difficult to identify small differences in sequences of numbers and letters unless they are highlighted. It may be better for one pilot to read out the clearance while the other checks it against the OFP/FMC, and then vice versa, to read the flight plan out while the other checks it against the clearance. The best chance to identify small changes is to start from the assumption that there will be a change rather than that there won't. Some operators also validate the planned heading between waypoints, as a small change in heading may allow an error to be identified early.

Take Off Performance Calculation and Entry Errors

B767-300ER, Manchester, England
13 December 2008

Case Study 3

Incorrect Take-Off Weight

Incorrect Take-off Weight
Boeing 767-39H, Manchester, England, 13 December 2008

The factual information for this serious incident was taken from the UK Air Accident Investigation Branch report, available at http://bit.ly/hZSPlU. The following study constitutes observations on the incident in the light of this report and does not purport to be an independent assessment of the incident. It is provided for the purpose of reducing the likelihood of future incidents, and does not seek to apportion blame or liability.

The Incident

The Boeing 767 was scheduled to operate from Manchester, England to Montego Bay, Jamaica, with 11 crew and 254 passengers on board. The pilots were from another base of company operations and the Captain was unfamiliar with Manchester airport. There was work in progress on the taxiways at Manchester.

Prior to boarding the aircraft the pilots passed the handling agent the data required to complete the loadsheet, and once on board they prepared the laptop computer take-off data application, known as the 'computer take-off program' (CTOP) by entering all of the relevant data with the exception of the take-off weight. The loadsheet arrived at the scheduled departure time and the CTOP data entry was completed with the entry of a weight in the take-off weight field. The take-off V speeds, calculated by the CTOP, and the associated reduced thrust setting, were entered into the flight management computer (FMC) and the aircraft was pushed back 15 minutes behind schedule.

As the aircraft was taxiing out it began to rain and the prevailing outside air temperature made it was necessary to switch on the engine anti-ice system, which in turn required a recalculation of the take-off speeds and thrust setting. The Captain continued to taxi the aircraft while the first officer ran the CTOP calculation again, with engine anti-ice on. The thrust and speeds were unchanged.

During the take-off roll the captain observed that the acceleration appeared 'sluggish' and he elected to delay the 'V_1' callout, although it was not clear from the report whether he also delayed the 'rotate' callout. Take-off rotation was slow and the engine instrument and crew alerting system (EICAS) 'tailskid' message activated as the aircraft became airborne. The Captain then applied full thrust but the stick shaker activated briefly after take-off and the first officer reduced the pitch attitude to allow the aircraft to accelerate, while still climbing.

After acceleration and flap retraction the crew completed the 'tailskid' checklist, jettisoned fuel and returned to land at Manchester, where only minor paint damage to the tailskid was found.

The Investigation

The report noted that the potential for time pressure (perceived or actual) upon the pilots at the time the take-off weight entry was completed in the appropriate field of the CTOP was due to the late delivery of the loadsheet. Subsequent recalculations indicated that the zero fuel weight (ZFW) from the loadsheet was entered in this field, instead of the take-off weight which was almost 55 tonnes greater, generating speeds approximately 20 knots less than those appropriate to the actual weight. It is likely that the reduced thrust value from the CTOP was also less than it should have been, although this is not mentioned in the report.

The investigation identified a number of factors which may have distracted the Captain from adequately checking the output data from the CTOP. In addition to the time pressure, his unfamiliarity with the ground environment in Manchester and the additional complication of work in progress on the taxiways may have drawn his attention away from the CTOP calculation. Furthermore, the Captain told investigators that he had recently completed several flights with an empty aircraft and hence the low take-off V speeds did not seem that unusual to him.

The second CTOP calculation to take account of engine anti-ice, completed by the First Officer as the Captain taxied the aircraft, wherein again the ZFW was used instead of the take-off weight was not recognized by the pilots, nor were the erroneous V speeds.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Airport Environment	
Meteorological	
Procedural	
Human	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the accident:

Observations for Facilitators

The substitution of ZFW for TOW in the take-off data calculation is not uncommon, even though the output data from the calculation process frequently offers speeds well below those appropriate to the actual weight, especially when operating long sectors with heavy fuel loads. Pilots familiar with their aircraft's performance might be expected to be alerted by such low speeds but this innate safeguard may be eroded by operating sectors of varying length and with significantly different aircraft weights.

Time pressure in the pre-departure phase, whether perceived or actual, internally or externally driven, is an operational reality which pilots have to manage. Rushing or abbreviating vital procedures like the take-off data calculation to save a few minutes may be severely counter-productive, as in this case. While the aircraft is still parked both pilots have ample opportunity to cross-check the output data but this is not necessarily true for recalculations required after push-back.

Operators must develop robust and error tolerant calculation procedures, that are 'user friendly' and not unduly time-consuming, and include adequate gross error checks. The operator made procedural changes following this incident, including a requirement for both pilots to complete independent CTOP calculations. However, although these changes encouraged pilots to make gross error checks of the loadsheet, no similar requirement was made for a gross error check of the CTOP output data. Timing and crew workload in the cockpit are essential elements of procedures that minimize risk and manage threats.

Distraction and task focus can lead to substantial oversights and omissions, even of operationally essential tasks like the cross-check of take-off data. Pilots must be constantly reminded of the risks of unfamiliar environments and the additional cognitive demands associated with them.

When the Captain observed that the acceleration was 'sluggish', his first action was to delay the 'V_1' callout. While he did eventually select full thrust at lift off, it would have been more appropriate to do so as soon as he felt concern with regard to the aircraft's performance, or indeed to reject the take-off while sufficient runway remained.

Workshop participants should identify some or all of the following threats:

Organizational – late delivery of loadsheet; time pressure

Airport environment – work in progress; task focus, distraction

Meteorological – rain, requirement for engine anti-ice; distraction

Procedural – error tolerance; requirement for inclusion of independent calculation

Human – Captain's unfamiliarity with environment, Captain's recent experience with light aircraft weights

And Errors:

- Time pressure management
- Selection of incorrect weight from loadsheet
- Inadequate entry data cross-check
- Inadequate output data cross-check/gross error check – failure to recognize inappropriate speeds
- Distraction and task focus
- Failure to select full thrust or reject when performance was in doubt (related to incident outcome not cause)

TEM Strategies:

Operator – as evidenced by the procedural amendments subsequent to the incident the operator recognized the need for more robust procedures for take-off data calculation. A combination of independent take-off data calculations by each pilot and effective gross error checks are most likely to be successful in avoiding and catching erroneous data entries before they occur.
exercises where potential takeoff data errors are highlighted and revised.

Individual – pilots must be aware of the threats posed by time pressure, task focus and distraction and develop their own strategies to recognize and manage them. It is also essential for pilots to have a sound general understanding of their aircraft's performance in terms of the relationship between fuel load, payload, runway characteristics and the V speeds likely to be associated with them. With regard to the outcome of the incident, whenever take-off performance is in doubt pilots should immediately decide either to apply full thrust or to reject the take-off.

B777-300ER, Auckland, New Zealand
22 March 2007

Case Study 4

Incorrect Take-Off Weight

Incorrect thrust and configuration for take-off
Boeing 777-300ER, Auckland, New Zealand, 22 March 2007

The factual information for this serious incident was taken from the New Zealand Transport Accident Investigation Commission report, available at http://bit.ly/gBpvBg. The following study constitutes observations on the incident in the light of this report and does not purport to be an independent assessment of the incident. It is provided for the purpose of reducing the likelihood of future incidents, and does not seek to apportion blame or liability.

The Incident

The Boeing 777 was operating a scheduled service from Auckland, New Zealand to Sydney, Australia with 2 pilots, 16 cabin crew and 357 passengers on board. A NOTAM (notice to airmen) was active for Auckland, notifying pilots that there would be work in progress at the upwind end of runway 05R, and that the available runway length would be reduced when advised by ATIS (Automatic Terminal Information Service).

The aircraft and crew arrived from Sydney approximately 2 hours earlier, and the runway length restrictions had been temporarily lifted to allow the departure of another aircraft. The pilots of the incident aircraft were advised by ATC that the full runway length was available for their landing.

Prior to departure the pilots obtained a printed copy of the ATIS information 'Q' from the ACARS (Aircraft Communications Addressing and Reporting System) and later confirmed that there had been no significant changes by listening to the VHF radio ATIS broadcast of information 'R'. The first officer entered the meteorological conditions from the ATIS in the take-off data laptop application (BLT) to calculate the thrust assumed temperature, the configuration and the V speeds, using runway 05R full length. These data were cross-checked by the Captain and entered in the Flight Management Computer (FMC).

Once on runway 05R the pilots set the thrust as calculated by the laptop and commenced the take-off roll with the first officer as pilot flying. Some distance along the runway the Captain observed vehicles on the runway at the upwind end and he selected TOGA (take-off/go-around or maximum) thrust. The aircraft quickly accelerated to rotate speed (VR) and the first officer rotated the aircraft to lift-off.

The Investigation

The investigation determined that the pilots had the relevant NOTAM available to them and that the ATIS (both 'R' and 'Q') included the information 'REDUCED RUNWAY LENGTH EASTERN END REFER NOTAM BRAVO 1203'. However, in the printed version, this information was on three separate lines of text and closely located with other information about go-around. The ATIS messages as a whole were rather longer than was usual and the broadcast included the words 'ACTIVE RUNWAY MODE NORMAL OPERATIONS', although this reference actually related to which airfield charts were to be used.

The vehicles were not visible to the pilots at the beginning of the take-off roll, in spite of daylight and good visibility, owing to the length of the runway (3230 meters). The NOTAM reduced the total runway length by 1060 meters.

The thrust and configuration used at the start of take-off were inadequate to achieve a take-off with the normal margins of safety in the reduced runway length available. However, with the application of TOGA the aircraft was airborne 190 meters before the end of the reduced length and it cleared the vehicles by approximately 28 meters vertically.

The investigation concluded that the pilots had adopted a mindset that the full length was available, possibly due to the full length being available when they landed and the words ‘NORMAL OPERATIONS’ in the ATIS messages. To quote the report, ‘the ATIS broadcast did not fulfill its intended purpose’.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Airport Environment	
Meteorological	
Procedural	
Human	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the accident:

Observations for Facilitators

This incident may at first appear very difficult to explain – two competent and experienced pilots overlooked critical operational information in a NOTAM and 2 ATIS messages. However, subtle factors combined to convince them that they would have the full runway length available for take-off. They had the full length available when they arrived and the ATIS messages started with the statement 'NORMAL OPERATIONS'. There was no additional clarification of the runway status from ATC prior to the departure.

Once the Captain observed the vehicles ahead he had 3 choices: do nothing and continue with the take-off; reject the take-off, or; apply full thrust and continue. None of these choices offered an assurance of success because the aircraft performance data were compromised by the use of incorrect runway length information. However, the decision to apply TOGA and continue the take-off turned out to be sound and a collision with the vehicles was avoided, albeit by a small margin.

Workshop participants should identify some or all of the following threats:

Organizational – ambiguous and lengthy ATIS; misunderstood by the pilots

Airport environment – work in progress during operational periods; requirement for changes to critical performance calculations

Meteorological – none; clear daylight conditions

Procedural – error tolerance; the existing procedures did not identify the error at the time

Human – mindset; the potential to adopt an inaccurate model of reality

And Errors:

- Failure to analyze and understand the ATIS message
- Acceptance of the least threatening scenario as a mindset
- No query to ATC to confirm runway status
- Use of incorrect input data for take-off performance calculation

TEM Strategies:

Airport Operator – reducing the available length of an active runway will always carry the risk of a take-off data error and consequent possibility of an overrun. If at all possible, work that temporarily affects the available length should be conducted only when the runway is closed. ATIS messages are required to convey vital information and should therefore be succinct and accurate. If there is any possibility of misunderstanding it should be clarified directly by ATC.

Aircraft Operator – pilots must be trained to assume the worst case scenario and work back from there, obtaining confirmations on the way. It should be mandatory to obtain confirmation from ATC that any temporary restrictions are not in force. Procedures for take-off data calculation need to be error tolerant and should include a step to confirm the existence of unusual environmental conditions.

Pilots – never accept that the most benign scenario prevails, especially in a situation that has the potential for temporary restrictions. Every take-off data calculation is critical and must be conducted with the utmost care and attention.

A330-243, Montego Bay, Jamaica
28 October 2008

Case Study 5

Incorrect Take-Off Weight

Incorrect thrust and configuration for take-off
Airbus A330-243; Montego Bay, Jamaica; 28 October 2008

The factual information on this serious incident was derived from U.K. Air Accidents Investigation Branch (AAIB) Bulletin 11/2009, report no. EW/G2008/10/08, available at http://www.aaib.gov.uk/publications/bulletins/november_2009/airbus_a330_243__g_ojmc.cfm. The following case study constitutes observations on the serious incident that are based on the AAIB's official report and does not purport to be an independent assessment of the incident. The case study is provided for the purpose of reducing the possibility of future flight management system (FMS) data input error events and does not seek to apportion blame or liability.

The Incident

The A330 was departing from Sangster International Airport in Montego Bay, Jamaica, for a scheduled flight with 318 passengers and 13 crewmembers to an unspecified destination in the United Kingdom.

The aircraft appeared to accelerate normally for takeoff on Runway 07 but the commander, as the pilot flying, was surprised at the unusually short intervals between the copilot's callouts of "100 knots", "V_1" and "rotate." At the call of "rotate," the commander pulled back on his sidestick as normal and the aircraft rotated to 10 degrees nose-up. However, it failed lift off the runway as expected and the commander selected takeoff/go-around (TOGA or maximum available) thrust. The aircraft subsequently became airborne and climbed away without further incident.

The Investigation

The AAIB concluded that an error in the calculation of takeoff performance data had led to the flight crew's use of incorrect takeoff speeds and an incorrect thrust setting.

The investigation found that after the flight crew reported for duty at 2145 local time, they were not able to locate the aircraft's performance manual, which had been stowed incorrectly among navigation charts on the flight deck. The commander therefore employed an alternative procedure approved by the operator for deriving take-off performance data: He telephoned the operator's flight dispatch office in the United Kingdom and requested that the calculations be performed using an Airbus take-off data computer application available at the office. The commander provided the necessary input information, including the take-off weight, airport weather conditions and runway data. The dispatcher entered this information into the application, which then calculated take-off V-speeds and a flexible take-off thrust (FLEX) temperature from which the reduced thrust setting could be calculated by the aircraft's FMS.

After receiving these data from the dispatcher, the commander handed the telephone to the copilot, to repeat the process as a cross-check before entering the calculated values in the aircraft's FMS. According to the procedure this second calculation was to be performed by a separate dispatcher or the duty pilot but although two dispatchers were on duty the second was not present and the repeat calculation was performed by the same dispatcher. No copy of the procedure itself was available to the crew.

Investigators also found that an available function of the application enabling the calculation of a "green dot speed" — engine out clean speed and best lift/drag ratio — had been disabled at the dispatch office. Without this information the crew was not able to perform a "gross error check" by comparing a computer calculated green dot speed with a green dot speed calculated independently by the FMS.

The takeoff performance figures provided by the dispatcher and entered in the FMS were checked again during the takeoff brief by the commander, the copilot and a supernumerary pilot who was an A330 line captain. No anomalies were detected.

The investigation found that a substantial discrepancy had gone unnoticed. The aircraft's load sheet showed a take-off weight of 210,183 kg but the input data logged by the dispatcher showed that the performance calculations had been based on an erroneous take-off weight of 120,800 kg. Investigators were unable to determine how this mistake was made, in part because the telephone conversations between the pilots and the dispatcher had not been recorded, and because the Cockpit Voice Recorder (CVR) data had been overwritten after the incident.

As a result of the mistake in the performance calculations, the crew entered 114 knots in the FMS for both V_1 and VR, whereas the correct figures were 136 knots and 140 knots, respectively. The crew also entered an erroneous flex temperature of 63°C, rather than the correct figure of 50°C, causing the FMS to calculate and command a significantly lower thrust setting than was appropriate.

The AAIB report said that the crew was not able to explain why they did not recognize that the take-off data values they used were not in the range they would normally expect to see. The factual information gathered during the investigation indicated that the crew was well-rested, but the report said that the take-off calculations were performed at a low point in their circadian rhythm and that their mental performance might have been affected.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Procedural	
Human	
Technological	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the incident:

Observations for Facilitators

Even when the conditions for fatigue are not present it is important to recognize that very similar symptoms may be caused by circadian low, and critically all crew members may be suffering similar symptoms at the same time. It is impossible to avoid circadian lows but it is possible to be aware of the potential effect on human performance, and to take additional care.

That humans will make errors is accepted as inevitable but how such large disparities between perception and reality can go unnoticed or at least unremarked is not well understood. It should have been clear to all involved that the take-off weight, the V-speeds and the flex temperature were inappropriate to the operation. Procedures and cross-checks are designed to help identify such errors but history shows that they cannot always be relied upon. The only computer-to-computer cross-check, the comparison of green dot speed calculated by the take-off data application and that by the FMS was not available on this occasion, although the reason it had been disabled was not determined. Until the FMS is able to detect and warn of a disparity between the weight and speeds entered by the crew, this is the only cross-check that isn't solely reliant on correct data transfer.

The performance of the second data calculation by the same dispatcher, rather than using a colleague as required by the procedure, removed a further opportunity for the erroneous values to be identified. However, bearing in mind the number of individuals involved already, there was no guarantee that the outcome would have been any different.

Once the Captain recognized that the aircraft performance was not as expected he applied TOGA thrust, the only real option left to him once above V1. This is somewhat unusual in these cases, as historically pilots have often left the thrust at the flex/reduced thrust setting until actually overrunning the runway end.

From the perspective of investigation, simple technological solutions like recording telephone conversations would help the understanding of the causes of these events.

Workshop participants should identify some or all of the following threats:

Organizational – reliance on a single manual on the flight deck for take-off data calculation; disabling the green dot calculation function without record of why; no copy of the remote data calculation procedure on the aircraft.

Procedural – absence of the green dot check; absence of a loadsheet versus FMS reconciliation.

Human – potential circadian low; tendency to accept computer generated data without question; complacency.

Technological – absence of the green dot check.

And errors:

- Failure to recognize that the take-off weight passed to dispatch was significantly less than that on the loadsheet and incongruous with the operation.
- Failure to identify that the take-off V-speeds and flex temperature were inappropriate
- Failure to follow the proper procedure in Dispatch

TEM Strategies:

Operator – circadian lows and tiredness are realities of the business but pilots (and other vital operational staff) must be educated and constantly reminded of the insidious degradation of human performance associated with them. If pilots are expected to use a back-up procedure but might only do so rarely, they should have a copy of that procedure available to follow – the first officer may have asked to speak to someone else. All operational procedures and processes, especially those associated with vital functions like take-off performance calculation, should be regularly analyzed to measure error tolerance and likely compliance.
exercises where potential takeoff data errors are highlighted and revised.

Individual – recognize that your performance might be impaired, and discuss it with your colleagues. If a procedure is at all unfamiliar, review it before implementing it. Accept that take-off data calculation is both vital and error prone and treat the process with the utmost caution. Know what 'normal' should look like for all phases of the operation and be ready to question anything that looks unusual. For the dispatcher, and any other operational staff, avoid any potential to circumvent an established procedure or skip a cross-check.

A340-642, London, England
12 December 2009

Case Study 6

Incorrect Take-Off Weight

Incorrect thrust and configuration for take-off
Airbus A340-642; London, England; 12 December 2009

The factual information on this serious incident was derived from U.K. Air Accidents Investigation Branch (AAIB) Bulletin 7/2010, report no. EW/G2009/12/04, available at **http://www.aaib.gov.uk/publications/bulletins/july_2010/airbus_a340_642__g_vyou.cfm**. The following case study constitutes observations on the serious incident that are based on the AAIB's official report and does not purport to be an independent assessment of the incident. The case study is provided for the purpose of reducing the possibility of future Flight Management System (FMS) data input error events and does not seek to apportion blame or liability.

The Incident

The A340 was departing from London Heathrow Airport for a scheduled flight with 282 passengers and 16 crewmembers to an unspecified destination.

The Pilot Flying (PF) noticed that the aircraft accelerated slightly more slowly than usual during the take-off roll, but he did not then consider the aircraft's performance to be particularly abnormal. During the take-off rotation he found that the aircraft felt "slightly sluggish and nose-heavy", and after lift off the airspeed settled below VLS — the lowest selectable airspeed that provides an adequate margin above stall speed. The PF reduced the pitch attitude a little to allow the aircraft to accelerate but as a result the rate of climb was low, at between 500 fpm and 600 fpm. At no time during the departure did the flight crew select TOGA (take-off/go-around) or full take-off thrust. The flight was continued to the destination without further incident.

The Investigation

The flow of pre-flight preparation by the crew was reportedly disrupted by a late change in the zero fuel weight (ZFW) and the pilots requested a new flight plan to account for the change. Apparently as a result of this change, the loadsheet and take-off performance data calculation procedures were not conducted in the normal order.

Take-off performance calculations were routinely managed by computer in a centralized facility, based upon the relevant information provided by the crew via the Aircraft Communications Addressing and Reporting System (ACARS). Normally, the crew would pass an estimated take-off weight ahead of time, from which the take-off data would be calculated but these data would not be entered in the FMS until the actual take-off weight was verified against the estimated value. However, because of the late ZFW change the crew elected to omit the estimated weight step of the procedure and send the actual take-off weight when it was available from the loadsheet.

When the information was later sent by the crew, the take-off weight was given as 236.0 tons (236,000 kgs), which the investigation found equated precisely with the predicted landing weight from the loadsheet, rather than the actual take-off weight of 322.5 tons. This incorrect weight was entered by ground staff into the take-off data computer application, resulting in speeds of VR (rotate speed) 143 knots and V_2 (take-off safety speed) 151 knots, and a flexible thrust (FLEX or reduced thrust) temperature of 74°C, whereas the correct values would have been 157 knots, 167 knots and 63°C respectively. The pilots entered the erroneous values transmitted back to them into the FMS and although they did discuss the high flex temperature, they did not ask for confirmation.

The take-off and climb were conducted using these incorrect values, which resulted in degraded acceleration and climb performance. In the circumstances there were no adverse consequences but had it been necessary to reject the take-off at or close to V1, or if there had been an engine malfunction at a critical time, then runway excursion or inadequate obstacle clearance may have ensued.

The investigation concluded that the late ZFW change, which apparently caused the pilots to diverge from the normal procedural sequence, and any consequent time pressure, could have contributed to the initial error in take-off weight and the subsequent failure to identify that the weight, speeds and flex were inconsistent with a flight of that length. Another factor in the failure to identify the anomaly may have been that the pilots operated a range of different flights at a range of operating weights and also flew the lighter weight A340-300 in a Mixed Fleet Flying (MFF) environment; therefore the parameter values may not have seemed unusual.

The operator subsequently reviewed loadsheet and take-off performance calculation procedures but the report concluded that the procedures were already robust and that adding more cross-checks would probably complicate the process with no guarantee that a similar event would be prevented. However, some other operators did use a data calculation application capable of generating a ‘green dot’ speed (engine out clean speed and best lift/drag ratio) from the take-off weight. This could be compared with the green dot speed similarly calculated by the FMS, which in this case was significantly different because the correct take-off weight (ZFW automatically summed with fuel on board) was available to the FMS.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Procedural	
Human	
Technological	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the incident:

Observations for Facilitators

Historically, distraction has been a major factor in many data entry errors and in this case the pilots appear to have been distracted from the normal pre-flight procedural flow by a slightly unusual (although operationally acceptable) change. A combination of distraction with time pressure, either perceived or actual, can often lead to divergence from SOP and to the inadvertent selection of incorrect data. SOPs must allow for the potential for disruption and company policy should be clear on the acceptance of delay when necessary to accommodate essential processes.

A potential 'non-procedural' safeguard was also circumvented by the fact that the pilots operated A340s at a variety of different weights and therefore were used to a wide range of data values. In the multi-fleet environment operators must ensure that their pilots are well aware of the consequences of this condition.

The green dot cross-check used by some Airbus operators offers a gross error check not solely based on pilot derived data values for the take-off weight, because the FMS uses a sum of ZFW and the fuel on board, rather than the take-off weight itself.

In view of the known frequency of this type of event, and the potentially catastrophic outcomes, pilots should always respond early to any unusual aircraft take-off/climb performance behavior. At low speed an immediate rejected take-off may be the best solution but at higher speeds above V1, selection of TOGA thrust without delay may be the only available option. In this event more than adequate runway length and the absence of critical obstacles allowed the take-off to proceed with harm but there have been many occasions when that has not been the case.

Workshop participants should identify some or all of the following threats:

Organizational – potential for late ZFW change to disrupt procedural flow; time pressure; Multi-fleet enviroment

Procedural – absence of the green dot check

Human – potential for distraction

Technological – absence of the green dot check.

And errors:

- Divergence from SOP
- Transmission of incorrect take-off weight
- Failure to identify that the take-off V-speeds and flex temperature were inappropriate
- No selection of TOGA when take-off/climb performance in doubt

TEM Strategies:

Operator – all operational procedures and processes, especially those associated with vital functions like take-off performance calculation, should be regularly analyzed to measure error tolerance and likely compliance. The significance of distraction and time pressure, whether real or imagined, in degrading human performance cannot be over stated and pilots should be constantly reminded to be wary of these factors. Company policy must be clear that delay is acceptable to allow for the conduct of safety critical processes. Any time that a normal procedure is interrupted during the critical phase of performance calculations, crews should be encouraged to take the extra time necessary to ensure errors are avoided. The delivery of data such as ZFW, and other activities in the latter stages of pre-flight preparation should be monitored for timeliness and frequent delays addressed as required. Some operators require that all performance data be delivered to flight crews before the aircraft leaves the gate, ensuring that a lower workload environment is available for this critical task.
exercises where potential takeoff data errors are highlighted and revised.

Individual – pilots must be constantly on their guard for the effects of distraction and time pressure, especially at critical times like just before departure. Procedures that are performed on every flight may appear to become routine and even mundane but they are there to protect against known human performance weaknesses, and should be adhered to for that reason. When the normal flow of crew coordination is interrupted it is important to use extra vigilance to ensure errors, particularly with regard to performance calculations, are avoided. Good guides for appropriate weight to V speed ratios can be of great value. Whenever aircraft performance is in doubt, take action immediately; during take-off either stop right away or apply TOGA and continue. The causes can be considered when safely airborne.

B747-300, Take-off Calculation Error, Changi, Singapore
2 June 2007

Case Study 7

FMS Data Input Error Serious Incident

Incorrect runway length used
B747-300 Take-off data calculation error; Changi, Singapore; 2 June 2007

The factual information on this incident was derived from the Singapore Air Accidents Investigation Bureau (AAIB) report AIB/AAI/CAS.040 dated 4 August 2008, available at http://app.mot.gov.sg/DATA/0/docs/mot_content/2%20Jun%202007.pdf. The following case study constitutes observations on the incident that are based on the AAIB's official report and does not purport to be an independent assessment of the incident. The case study is provided for the purpose of reducing the possibility of future flight management system (FMS) data input error events and does not seek to apportion blame or liability.

The Incident

The Boeing 747-300 aircraft was operating on a scheduled passenger service from Singapore Changi Airport to Riyadh, Saudi Arabia with a total of 388 persons on board.

Runway 20C was in use and there was a NOTAM (notice to airmen) in force warning that the take-off run available (TORA) for the runway was reduced from the normal 4,000 metres to 2,500 metres. To calculate the take-off performance data the pilots were supplied with faxed copies of take-off data charts with 8 columns, each corresponding to a runway, including runway 20C with the reduced TORA.

During the take-off roll all three cockpit crew members observed red runway lights approaching, indicating that the aircraft was nearing the runway end. However, the Captain, as Pilot Flying (PF) apparently made no changes to the thrust and rotated the aircraft normally.

The controller on duty observed that the lighting of some marker boards at the runway end had been extinguished as the aircraft passed them on take-off and inspection found damage commensurate with aircraft tire impact.

The Investigation

The NOTAM regarding reduced TORA on 20C was not included in the pack of papers provided to the crew but the condition was highlighted to them by the dispatcher, and the flight engineer reported this as confirmed by the automated terminal information service (ATIS) prior to departure. The investigation concluded that the crew were aware that they would be taking off from a shortened runway.

Take-off performance data was calculated using faxed copies of computer generated charts, each with 8 columns for individual runways, including both the full length of runway 20C and next to it the reduced TORA 20CT. The crew reported that they had not seen this format of take-off chart before and the first officer asked the Captain to confirm which column to use. The Captain indicated the correct reduced TORA 20CT column but the crew later concluded that the first officer then erroneously used the full length column to calculate the data. The correct associated runway lengths were shown on these charts but appeared on the next page to the take-off data columns.

The operator's procedures did not call for any cross-check of the take-off data obtained by the first officer. While it cannot be proven that a cross-check would have revealed the error, it is certainly a possibility.

The report indicated that the investigators were unable to obtain the Flight Data Recorder (FDR), Quick Access Recorder (QAR) or Cockpit Voice Recorder (CVR) data, and therefore the precise details of aircraft behaviour could not be analyzed. However, from the damaged signs and eyewitness reports it appeared consistent with having used the full length runway 20C performance for the take-off. Subsequent calculations indicated that at the actual take-off weight of 337,504 kgs it would not have been possible to get airborne in 2,500 metres, within the regulatory margins of safety.

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Organizational	
Environmental	
Procedural	
Human	
Technological	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the incident:

Observations for Facilitators

Runways shortened due to work in progress have contributed to several incidents and accidents in which data for the incorrect runway length have mistakenly been used. As in this case it seems that even if the crew members are aware that the planned departure runway has been shortened, it is still possible to erroneously use the full length data. Work in progress is a threat generally, and especially at new or expanding airports where runway and taxiway layouts, and associated procedures, may have changed since a pilot's last visit.

Error in complex human activity is almost inevitable and it is vital that robust cross-checks are in place to ensure that an error by an individual can be detected by other members of the crew. Individuals are most unlikely to detect an error of their own, once committed. Furthermore, the use of gross error checks to confirm that the data being used is at least reasonable, have been used with some success in detecting fundamental errors. Computer based data calculation applications, while not error proof, have greater potential for the incorporation of data integrity checks and protections against improper selection.

Without the recorder evidence it cannot be shown whether any of the crew responded to the rapidly approaching runway end lights but the absence of any reference in the report suggests not. At that late stage there was only the option of selecting TOGA thrust to ensure the earliest lift off and best climb performance.

Workshop participants should identify some or all of the following threats:

Organizational – absence of NOTAM from flight pack; use of faxed take-off charts; use of unfamiliar charts

Environmental – runway TORA reduced by work in progress

Procedural – absence of cross-checks; absence of gross error checks

Human – complacency

Technological – use of paper charts rather than electronic flight bag

And errors:

- Mistakenly using full length 20C column for data calculation
- Failure to cross-check (even though not required)
- Failure to gross error check (even though not required)
- Absence of response to approaching runway end (possibly)

TEM Strategies:

Operator – pilots should never find themselves in a situation where something as important as take-off data calculation requires the use of unfamiliar data sources or tools. If the operator plans to use more than one system then it is essential that all pilots have been trained fully in the use of each of them. The dispatcher was aware that the reduced TORA was in use and could have been requested to highlight that column on the faxed chart copies. All critical calculations and selections require procedural cross-checks and any complex calculation should be followed by a gross error check. A proactive watch should be maintained for work in progress at airfields network wide and new threats highlighted to crews.

Individual – never accept important information at face value. Even if the procedures do not require a cross-check pilots should be comfortable with doing one of their own, certainly when safety of flight is at stake. If aircraft take-off or climb performance is in doubt then take immediate action; late in the take-off roll the only option may be selection of TOGA thrust. Always be especially wary at airfields with work in progress.

B747-400 Take-Off Data Calculation Error; Orly, France; 10 December 2006

Case Study 8

Incorrect FMS Data Input

B747-400 Take-off data calculation error;
Orly, France; 10 December 2006

The factual information on this incident was derived from the French Bureau d'Enquetes et d'Analyses (BEA) report available (in French) at **http://www.bea.aero/docspa/2006/f-ov061210/pdf/f-ov061210.pdf**. The following case study constitutes observations on the incident that are based on the BEA's official report and does not purport to be an independent assessment of the incident. The case study is provided for the purpose of reducing the possibility of future flight management system (FMS) data input error events and does not seek to apportion blame or liability.

The Incident

The Boeing 747-400 aircraft was scheduled to operate a long haul passenger service from Paris-Orly airport to the Antilles, with 15 crew and 563 passengers onboard.

On arrival at the aircraft the pilots found that one of the two laptops having the 'Boeing Laptop' (BLT) take-off performance data calculation application had a fully discharged battery and could not be used. Furthermore, a technical fault with a fuel scavenge pump meant that the crew had to consider 1.6 tonnes of fuel operationally unusable. During the pre-flight preparation the first officer observed indications of a hydraulic system fault and the engineer confirmed that it was being rectified.

The first officer used the serviceable second laptop's BLT application for the initial take-off data calculation. The Captain read out the Zero Fuel Weight (ZFW) and Take-Off Weight (TOW) from the loadsheet and the first officer entered the ZFW in the FMS and the TOW in the BLT application. The Captain had added 1.6 tonnes to the ZFW to account for the unusable fuel. The first officer entered the other required parameters in the BLT to calculate the take-off speeds, assumed temperature for reduced thrust and flap setting, and then passed the laptop to the captain for confirmation. At the time the Captain was also discussing the hydraulic fault with the engineer.

Later, the first officer found that he had inadvertently turned the laptop off, and the previously entered parameters had been erased. It was necessary once again to ask the captain for the TOW before he could perform a new calculation. When this was complete the captain entered the speeds and assumed temperature from the BLT into the FMS, replacing those calculated by the FMS itself. He queried the assumed temperature as it seemed high but the first officer explained that it was due to the low outside air temperature and high pressure.

The aircraft departed from the parking stand, taxied out and initiated a 'rolling' take-off. At V1 (take-off decision speed) the pilots began to recognise that the take-off performance was not normal and the Captain as pilot not flying decided to delay the call for rotation. When the first officer did commence rotation he found that the aircraft was heavy in response, and as pitch attitude began to increase the 'stick-shaker' stall warning activated. The first officer reduced the pitch input and applied full take-off thrust, and the aircraft became airborne.

A runway inspection found metallic debris on the end of the runway and suspecting damage the aircraft returned to land after jettisoning fuel.

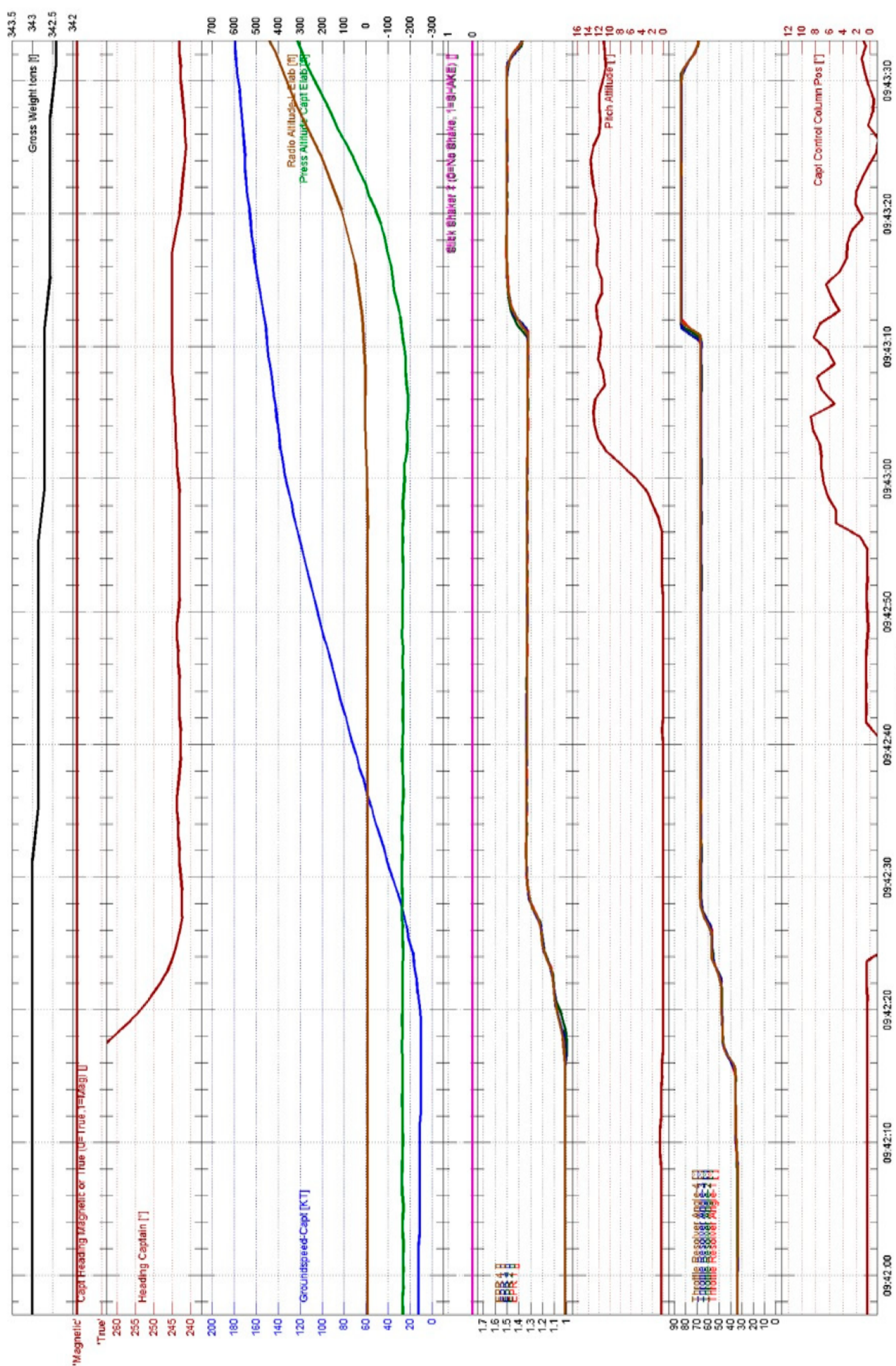
The Investigation

On the second occasion that the first officer requested the TOW, the investigation concluded that the Captain read out the ZFW instead but neither pilot recognised the discrepancy. As a result the first officer entered a weight some 100 tonnes below the TOW in the relevant field of the BLT. The BLT calculated the take-off data based on this erroneous weight and generated speeds (V1, VR and V2) approximately 30 knots lower than required, and an assumed temperature 9°C too high.

The FMS also automatically calculated V speeds and assumed temperature, based upon the ZFW and fuel on board, which were in fact much closer to the correct values. However, because the FMS did not have access to all of the variable parameters used in performance calculations (pressure for example), the existing procedure required the crew to overwrite the FMS values with those from the BLT, which the captain did *after* the second erroneous calculation. The first officer subsequently checked that the FMS and BLT speeds and assumed temperature matched, which they did.

The recorded flight data (below) showed that full take-off thrust was applied several seconds after rotation commenced and as the aircraft lifted off. This was simultaneous with activation of the stick shaker. Evidence of tailstrike was found on the aircraft aft fuselage after landing.

The recommendations of the report indicate that distraction may have been a factor during the critical phases of take-off performance calculation.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Capt Heading Magnetic or True (0=True,1=Mag) []
Heading Captain [°]
Groundspeed-Capt [KT]
Radio Altitude-L Elab [ft]
Press Altitude Capt Elab [ft]
Stick Shaker 1 (0=No Shake, 1=SHAKE) []
EPR 4 []
EPR 3 []
EPR 2 []
EPR 1 []
Pitch Attitude [°]
Throttle Resolver Angle-4 [°]
Throttle Resolver Angle-3 [°]
Throttle Resolver Angle-2 [°]
Throttle Resolver Angle-1 [°]
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09:42:20
09:42:30
09:42:40
09:42:50
09:43:00
09:43:10
09:43:20
09:43:30

Based on the foregoing, list the THREATS (external factors) encountered by the crew:

Operational	
Technological	
Procedural	
Human	

List the ERRORS (internal factors) made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the incident:

Observations for Facilitators

The distraction risk presented by a single factor, the hydraulic problem for example, may be quite easy to recognize and manage but the cumulative risk of multiple distractions is much harder to predict. In this case they had a failed laptop requiring a process modification, a fuel pump fault requiring manipulation of procedures and weights, an inadvertent off selection of the laptop requiring a second calculation, a hydraulic fault requiring crew attention in addition to the usual functions of pre-flight preparation.

The opportunity for a valuable gross error check using data from different sources appears to have been missed when overwriting the FMS speeds with those from the BLT. A substantial discrepancy between the two calculations, as in this case, should have been cause for investigation by the crew. A second innate gross error identification opportunity was missed when the first officer was able (incorrectly) to explain the high assumed temperature following the captain's query. Pilots should be reminded that any question over critical data should be properly resolved.

Whenever there is any doubt about aircraft performance during take-off and initial climb, pilots should be ready to act positively and promptly. In the early part of the take-off roll a rejected take-off may be appropriate but later, especially after V1, immediate application of full thrust may be the only option.

Workshop participants should identify some or all of the following threats:

Operational – absence of sterile cockpit during take-off data calculation

Technological – absence of reliable laptop power supply; loss of BLT data at switch off

Procedural – weak procedure error tolerance; absence of gross error check when available

Human – distraction; complacency

And errors:

- Inadvertent selection of laptop to off
- Reading out ZFW instead of TOW
- Failure to recognize weight/speed/assumed temperature discrepancies
- Overwriting FMS values without questioning the difference
- Incorrect explanation for high assumed temperature, and its acceptance
- Late recognition and response to aircraft performance anomalies

TEM Strategies:

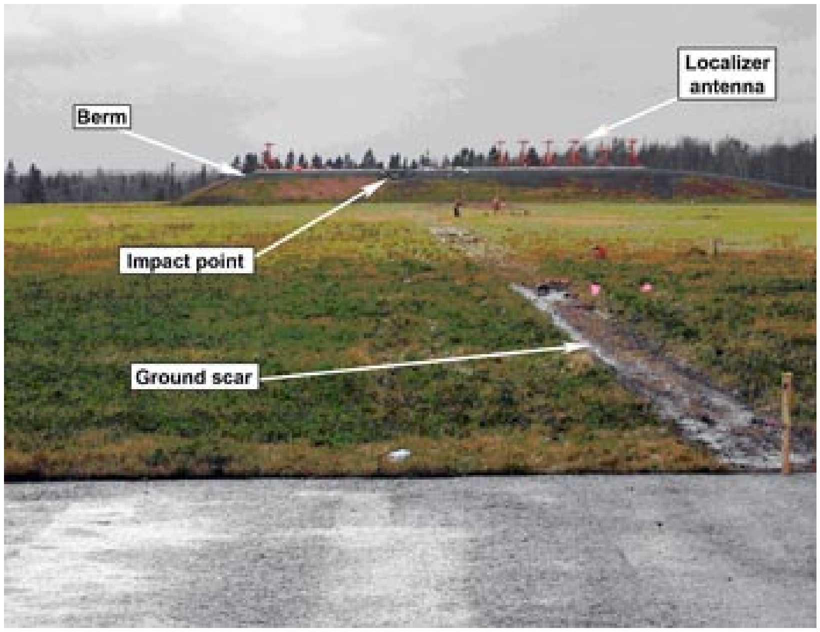
Operator – with the knowledge that pilots can be distracted from even the most vital tasks, it is essential to have a standard procedure for sterile cockpit during the take-off data calculation process. Other personnel like engineers, cabin crew and dispatchers should be briefed on this so that they understand why they must abide by the sterile cockpit. All critical processes should be regularly reviewed to ensure that they are as error tolerant as possible, and should always include robust gross error checks. Pilots should be trained in how to respond to anomalous aircraft behaviour during the take-off roll.
exercises where potential takeoff data errors are highlighted and revised.

Individual – always be aware of the potential for distraction at critical phases of the operation, and don't be afraid to ask other personnel to wait when an important process is being completed. If in doubt about any important parameter it should be re-checked, even if that means another complete calculation. Even if a procedure has no gross error checks, individuals may be able to develop their own, which will help to highlight major discrepancies. It is essential to be able to recognize anomalous aircraft behaviour during take-off and to react promptly and appropriately.

B747-400 Take-Off Data Calculation Error; Halifax, Canada; 13 October 2004

Case Study 9

Incorrect Take-off Weight - Runway Excursion
Boeing 747-200, Halifax, Canada, 14 October 2004



The factual information on this accident is taken from the TSB Canada final investigation report available at http://www.tsb.gc.ca . The following study constitutes observations on the accident in the light of this report and does not purport to be an independent assessment of the accident. It is provided for the purpose of reducing the possibility of future runway excursions, and does not seek to apportion blame or liability.

The Accident

The 747-200 freighter was operating a sequence of flights, which originated from Luxembourg on 13 October 2004, via Bradley Airfield, Halifax, Zaragoza and back to Luxembourg, with a heavy flight crew of 2 captains, 1 first officer and 2 flight engineers, a loadmaster and a ground engineer.

The aircraft commenced take off from runway 24 at Halifax at 0653 local time in darkness. The thrust was advanced to the pre-selected EPR of 1.33 and the aircraft accelerated to 130 knots, at which point take off rotation commenced some 5500 feet from the start of the take off roll. The pitch attitude increased to 9°, then 11° and the aft fuselage contacted the runway with 800 feet remaining to the upwind threshold. Shortly thereafter the thrust levers were advanced further and the aircraft passed the runway end at 152 knots and 11.9° nose up, with the aft fuselage but not the main wheels in contact with the ground.

The aircraft finally separated from the ground 670 feet beyond the end of the paved surface but seconds later the aft fuselage impacted upon an earthen berm, topped with a concrete plinth accommodating the ILS localiser antenna, 1150 feet beyond the runway end. The tail section detached from the aircraft, which then pitched down and impacted a wooded area nose first with severe structural break up and an intense fire. All seven crew members were killed.

The Investigation

The investigation determined that the crew had probably used a take-off weight of 240,000 kgs (529,109 lbs), which was equal to the take-off weight for the preceding sector, to calculate the take-off thrust and V speeds they inserted into the flight management computer (FMC). This was more than 100 tons less than the load sheet take-off weight of 350,698 kgs (773,156 lbs), which in itself was less than the actual weight due to some organizational and procedural deficiencies at the operator and at the ground handling service provider. The laptop application (BLT) used for the take-off data calculation defaulted to the take-off weight value inserted for the previous calculation until such time as it was updated by the crew. The investigation suggested that crew members had not undergone any formal training in the use of the laptop application.

Use of the incorrect defaulted take-off weight in the input data to the laptop, resulted in an 'assumed temperature' for significantly reduced take-off thrust (1.33 EPR) whereas for the actual take-off weight no thrust reduction was appropriate (1.60 EPR). Similarly the take-off V speeds calculated for the incorrect weight were much lower than those required for the actual weight.

The reduced thrust generated in response to the assumed temperature inserted into the FMC was insufficient to accelerate the aircraft to V_{mu} within the runway length and the calculated VR was significantly below V_{mu}. Company procedures required an independent cross-check of the take-off data from the laptop and a gross error check when setting the V speeds, but the investigation indicated that these may have been omitted.

At the time of the accident the flight crew had been on duty for almost 19 hours and were at a period of circadian low. The planned sequence of flights called for a total duty period in excess of the maximum permitted by the operations manual. The investigation also identified a level of personal stress amongst employees generally, due to prolonged absences from their families and the political/security situation at home. There was evidence that most if not all of the crew had undergone no training in the use of the laptop BLT application.

The crew failed to observe that actual aircraft performance during the take-off roll was inadequate to permit it to get airborne within the runway length, until it was too late to prevent a runway excursion. The aircraft did actually get airborne beyond the end of the runway, and was probably capable of returning to a safe landing in the absence of the impact with the berm. However, the berm was not considered an obstacle for take-off performance as it did not penetrate the surface of the obstacle free zone.

Based on the foregoing, list the THREATS encountered by the crew:

Organizational	
Meteorological	
Procedural	
Human	
Other	

List the ERRORS made by the crew:

List some CONTROLS, DEFENSES and TEM (Threat & Error Management) strategies that could have been used to prevent the accident:

Observations for Facilitators

Accidents and incidents of this nature are shockingly common and it is contrary to the basic principles of risk management to allow a single error or omission to lead to such catastrophic outcomes. While cross-check procedures developed by the operator should have identified such errors, time pressure, fatigue, complacency and numerous other factors will inevitably circumvent them on occasion and they cannot alone constitute a safeguard.

The fundamental issue is that of using the unreliable human to provide the link for vital data transfer in and out of a sophisticated and relatively reliable machine; the laptop computer. Secondary to this is the absence of any automated gross error check; a system as complex as a 747 should be able to determine that the response it has been programmed to give is potentially fatal.

In this case there was a significant functional deficiency in the laptop application, in that the take-off weight field defaulted to the last entered value, rather than a blank or 'void' field to remind users to enter the correct value.

The thrust remained at 1.33 EPR until shortly before the aircraft left the runway – earlier selection of full thrust may have avoided the accident.

Workshop participants should identify some or all of the following threats:

Organisational – inadequate training (laptop); inadequate fatigue risk management
Meteorological – none other than darkness
Procedural – inadequate safeguards built in, vulnerable to non-compliance
Human – fatigue and circadian low; inadequate training; personal stress; non-compliance
Other – (industry-wide) failure to recognize the implication of defaults in laptop applications; lack of measures to assist in recognition of inadequate aircraft performance

And errors:

- Failure to recognize or respond to symptoms of fatigue
- Failure to identify/address personal lack of understanding of laptop application
- Lack of recognition of incorrect take-off weight default value
- Apparent absence of laptop data cross-check
- Apparent absence of V speed gross error check
- Failure to identify/address inadequate aircraft performance in time (outcome rather than cause)

TEM Strategies:

Operator – with safety critical activities like take-off data calculation it is vital that pilots are adequately trained and tested in the use of the associated equipment. As important is to provide them with error tolerant procedures and robust gross error checks to validate the data they use. Automated systems such as the laptop BLT application should be rigorously examined for potential deficiencies like the take-off weight default, before they are brought into service. Fatigue management strategies are required to ensure that pilots are fit for the duties expected of them and less prone to simple errors.
exercises where potential takeoff data errors are highlighted and revised.

Individual – the primary responsibility of any individual engaged in high risk activities is to ensure that he is fit to carry them out. That includes fitness in terms of professional and procedural knowledge as well as medical health, and must be supported by a commitment to address the condition or withdraw from service until it is addressed. Also vital is to adopt what James Reason called 'mutual mistrust'; a polite but ever-present desire to question the actions of colleagues and the responses of technical equipment. Self-discipline is required to combat the natural tendency to 'practical drift' (divergence from procedure over time), and 'denial' (the perceived dilution of risk through repeated harmless exposure). Finally, an intimate understanding of the 'normal' behavior of the aircraft will allow earlier recognition of performance abnormalities.

FMS Errors and Anomalies
Selected Reports from NASA ASRS

Case Study 10

Incorrect FMS Data Input

FMS Errors and Anomalies
Selected Reports from NASA ASRS

The following reports are copied directly from NASA's ASRS (Air Safety Reporting System) database http://www.37000feet.com and all refer to errors in FMS entries or unexpected FMS behaviours, mostly following changes of clearance from ATC. They are not reproduced to suggest any judgment on the performance of the individual crew members or air traffic controllers but to illustrate the potential for erroneous entries or unexpected FMS behavior during flight.

Report 1

MD88 flight crew fails to program the meridian transition on the SOLDO RNAV SID from DFW. Track deviation results

We were notified by DFW that we were south of course; and were given a vector to rejoin the departure. The error was due to my failure to select the MEI transition when programming the FMS. This resulted in dropped fixes on the SOLDO2 departure from DFW and led us to proceeding direct MEI early. Our new flight plan may have caused me to miss the transition but ultimately it was my failure to verify it on the SOLDO2. An additional factor was our focus on not exceeding airspeed restrictions early in the departure. We had to leave our slats extended to make the airspeed and altitude restriction.

Report 2

An A320 crew failed to properly program the FMS for an HPN BRUNO arrival. As a result a track deviation occurred while the crew simultaneously performed a TCAS TA maneuver

Flight to HPN we were given the BRUNO3 arrival. The FMS was programmed for said arrival however during pre-flight/route insertion the route was mistakenly not double checked. As we were descending on the BRUNO arrival around intersection SOUND, ATC gave us direct BDR VOR. After BDR the FMS auto sequenced to ZOMBI intersection on the ILS runway 34 rather than to ALIXX and then to RYMES. There was a traffic conflict that arose as we turned to ZOMBI. We climbed to avoid traffic and then air traffic control gave us vectors to the airport. I am not sure why the FMS auto-sequenced. Upon further review of the air carrier airport briefing guide there was instruction to look out for this. Better pre-flight preparation would have helped by looking over the airport briefing more thoroughly.

Report 3

Flight crew of E140 fail to program revised route into FMC prior to takeoff. Track deviation noted by radar controller

Filed flight plan: DFW TRISS2 TXK J131 LIT J66 MEM DCU HSV. ATC revised flight plan DFW TRISS2 TXK J42 MEM DCU HSV. Shortly after TXK ATC notified us that we were slightly north of J42. Corrected back to J42. ATC confirmed the noted correction and passed us to ZME. ZME cleared us direct DCU. No apparent conflict and uneventful transition to ZME.

Report 4

CL65 crew did not program the ATC cleared route into the FMC, which caused a track deviation in ZLA Class A airspace

Filed clearance was: PHX DRAKE1 direct BLD J92 LMT direct EUG. Clearance received: PHX DRAKE1 J92 BLD as filed. First officer copies clearance: PHX DRAKE1 J92 BLD direct LMT direct EUG. As we overflew BLD, the FMS turned us direct to LMT. Lax gave us a vector towards BTY (on J92 after BLD) before going into a restricted area. We then discussed the clearance that we were given. I think if the clearance was given as PHX DRAKE1 J92 LMT confusion would have been avoided. Another solution would be to have company file the clearance the same as given by PHX clearance delivery.

Report 5

MD88 flight crew fails to catch their FMS program error while en route on a STAR arrival. ATC catches the off course deviation and sends them direct to their next point

Flight departed IND via the DAWNN1 departure/BWG transition and was flight planned to ATL via the ROME8 arrival from BWG. Shortly after passing BWG, ZME requested our next navigation fix, we responded RMG and center stated he showed our position east of course. We were now 20-40 NM south of BWG heading 160 degrees to RMG. FMS was operational and being tracked by autopilot. At this point we determined the transition over BWG had not taken us via the ROME8 BWG transition but directly to RMG (heading approximately 15 degrees east of course). As we were checking our position, center stated no problem and just proceed direct RMG. Flight continued without incident. 2 possible causes were discussed by flight crew.

1) On initial FMS programming the arrival transition, which shared a common fix with the departure transition accepted the common fix of BWG but was entered in such a manner the FMS took the entry as a request for direct BWG-RMG and not the BWG transition to RMG
2) The FMS was programmed as flight planned and a subsequent entry changed the transition to a direct leg. Both pilots had reviewed the data entry on pre-flight. Route and flight plan were verified. Crew believes they would have noticed the difference in heading/route as change from departure chart to arrival chart was made. This was in process of happening after passing common point of BWG and about the time center contacted the flight.

Report 6

Fokker 100 flight crew allows their FMC to program a speed deviation on a departure procedure

We were flying the usual SID departure from our home base, and departure had just handed us off to ZTL. The SID incorporates a 280 KT speed limit until advised by ATC to resume normal. The first officer was flying and I was making a PA to the passenger when the handoff occurred. When I finished the PA, I reported to the first officer that I was back. We had by that time received a clearance to 13000 ft and the first officer had initiated the climb. Clearance to resume normal speed is almost always given on initial contact with center but this time was an exception. The first officer made the climb to 13000 ft in the 'profile' mode which allows the computer (FMS) to determine optimum climb speed unless the pilot specifically overrides, and this was not the case. When the 13000 ft altitude was captured, the aircraft leveled and accelerated to 310 KTS. Within a very short time ATC asked us to confirm 280 KTS because there was traffic (same direction) 5 1/4 mi ahead. We immediately reduced speed. I do not believe a conflict occurred. This goof was my fault for not insuring that the first officer inserted a manual limit of 280 KTS in the FMS. The PA could have waited another few minutes. The first officer and myself were both a little fatigued by the amount of 'sitting around' time on this particular trip series.

Reference:

- ATSB TRANSPORT SAFETY REPORT Aviation Research and Analysis Report – AR-2009-052 Take-off performance calculation and entry errors at http://www.atsb.gov.au/media/2229778/ar2009052.pdf:
- Safety Trend Evaluation, Analysis and Data Exchange System: Analysis on Calculation / Input Errors: FMS Events
- An article titled “Fumbled Numbers” found in the Flight Safety Foundation AeroSafety World Magazine dated September 2010 at www.flightsafety.org