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FMS Data Entry Error Prevention Best Practices

1st Edition

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FMS Data Entry Error Prevention Best Practices
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Introduction

In the space of 40 years the flight management system (FMS) has evolved from a simple navigation management device into a fully integrated aircraft management system, receiving inputs from sensors in all flight critical systems and providing outputs that control virtually every aspect of the aircraft's behavior. The FMS has delivered efficiencies in aircraft management that are far beyond the capabilities of the human pilots however some data required by the FMS must still rely upon the human, either pilots or other external parties, to obtain and enter by its variety of interfaces. It is within these interactions that errors, some with catastrophic results (see Case Studies below), can occur.

A total of 309 air safety reports (ASRs) involving FMS data entry error were identified in the IATA Global Aviation Data Management (GADM) / Safety Trend Evaluation, Analysis & Data Exchange System (STEADES) program between 2007 and 2011. Based on total flights operated by GADM-STEADES members during this period, these 309 reports extrapolate into approximately 2,377 global industry events over five years or one (1) event per day.

Analysis of the reports showed that errors related to navigational data, potential for a Mid Air collision or Controlled Flight Into Terrain (CFIT) accident, accounted for 80% of the reports, while 20% were related to performance data and associated LOC-I or runway excursion accident. The analysis also shows that Air Traffic Control (ATC) related threats, cited in 27% of the reports, were the top contributor to FMS entry errors. Route modifications instructed by ATC; runway, departure and arrival changes; and revised altitude and speed instructions were commonly reported factors. These changes require the flight crew to modify the programed vertical and horizontal trajectories in the FMS, potentially introducing errors, distractions and increased workload especially during critical phases of flight.

Other reported threats such as aircraft malfunction, cabin events, ground events and dispatch/paperwork provided further evidence that flight crew distraction during FMS programing, and in particular during the busy pre-flight phase, frequently contribute to data entry errors. In addition to inadequate management of these external threats, a significant source of reported FMS entry errors was flight crew interaction with the FMS Control & Display Unit (CDU). Errors made when using FMS key pad/CDU during programing were the main reported data entry errors. Significantly, in 44% of the reports these errors went unnoticed by the pilots due to failures in monitoring and cross-checking. The reports also suggest that poor situational awareness and inadequate crew resource management led to flight path deviations following FMS data entry errors. In 35% of all reports, flight path deviations were first recognized by ATC rather than by the pilots, indicating inadequate error recognition and management.

This guide aims to analyse the threats which are known to promote and propagate these errors, to explore the common error types that have been identified in previous incidents and propose some strategic and tactical measures to help pilots and operators to prevent, identify and manage FMS data entry errors. The guidance is not intended to replace or contradict International Civil Aviation Organization (ICAO) Standards & Recommended Practices, State regulations, IATA International Operational Safety Audit (IOSA) Standards or manufacturers' procedures and guidance. Air carriers should always comply with the regulations and requirements of the relevant Competent Authority.

Case Studies

Tailstrike and runway excursion, Airbus A340-541 at Melbourne, Australia, 20 March 2009:

The flight was to operate from Melbourne, Australia to Dubai, United Arab Emirates with a ‘heavy’ crew of four (4) pilots, 14 cabin crew and 257 passengers. In accordance with company procedures the operating first officer entered the required data into the laptop take-off performance application and recorded the output values. The captain reviewed the data and entered the V speeds, the flap setting and the flex thrust temperature into the FMS. The aircraft was taxied to runway 16 for take-off, with the first officer as pilot flying. At V_R the captain called ‘rotate’ but seeing that the rotation did not commence, he called ‘rotate’ again. The aircraft pitched up but did not lift off and the rear fuselage contacted the runway surface. As the end of the runway was reached the captain selected TOGA (take-off/go-around or maximum) thrust but the aircraft main wheels and rear fuselage remained in contact with the ground in the overrun area for some distance before becoming airborne. After lift-off one of the main wheels impacted upon the ILS localiser antenna. The aircraft returned to Melbourne and landed safely.

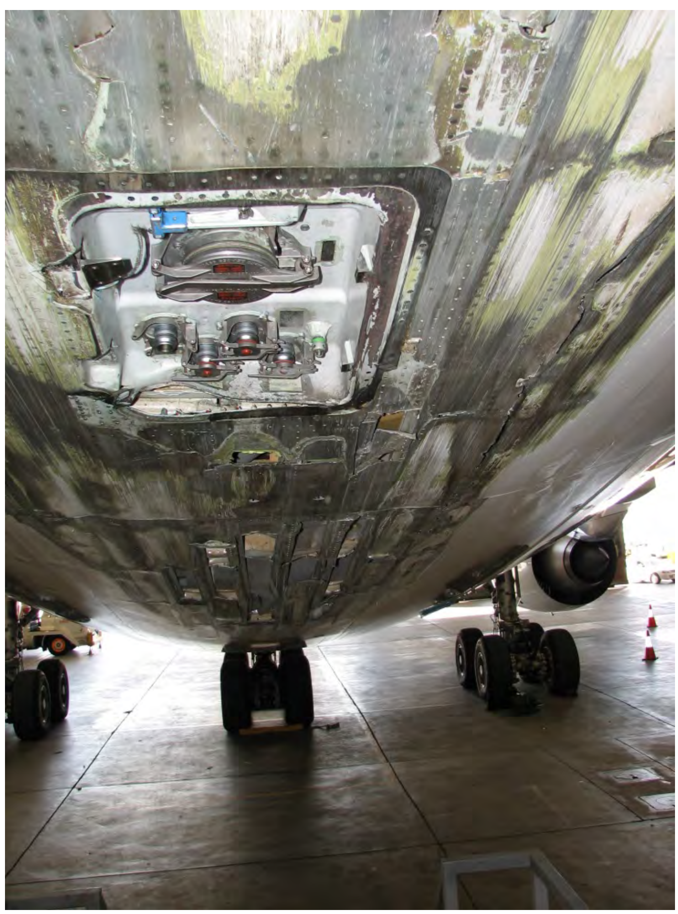

Figure 1: A340 Tailstrike Damage

Controlled Flight Into Terrain – Boeing 757-223 near to Cali, Colombia, 20 December 1995:

The flight was a scheduled passenger service from Miami, USA to Cali, Colombia with two (2) pilots, six (6) cabin crew and 155 passengers on board. On arrival 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 one (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 determined that the pilots had erroneously entered an incorrect navigation aid identifier into the FMS.

FMS Technology

As long range commercial aviation began to grow in the 1950s and '60s the demand for more versatile and accurate navigation systems grew with it. Flights over remote areas were able to supplement celestial navigation with inertial navigation systems (INS) and by the '70s aircraft were being equipped with navigation and performance computers. In the early '80s the first integrated flight management systems appeared, combining navigation and performance functions in a single system and ultimately contributing to the demise of the flight engineer role.

Modern FMS vary from simple navigation/performance computers to sophisticated control and computation systems, drawing data from multiple sources and providing numerous outputs to the aircraft systems, to the pilots and even to ATC, maintenance providers and airline dispatchers, remotely to the aircraft. The accuracy of the present generation of FMS allows for the reliable prediction and guidance of vertical and horizontal aircraft trajectories along with precise thrust management to optimize fuel efficiency and aircraft utilization.

However, there has long been a concern as to what effect these systems have on the role of the pilots and in particular the implications for cockpit workload. While the FMS undoubtedly absorbed many of the functions previously performed by humans, one early study published by NASA ('Human Factors of Advanced Technology Transport Aircraft', Earl Wiener, 1989) even concluded that while the FMS may decrease cognitive workload for the pilots when workload is low they potentially increase it when workload is already high. In its current form the FMS continues to require significant interaction from the pilots, entering data, making selections and crucially monitoring and cross-checking the system outputs. With the exception of the very latest aircraft types, the design of the FMS CDU, through which much of the interaction occurs, has changed little since the earliest incarnations. However, increasingly FMS software programs are including internal gross error checking functions to highlight potentially erroneous inputs.

Human Performance

Bearing in mind that the human brain has changed very little in hundreds, if not thousands of years it has assimilated remarkably well into the complex world of aviation, adapting to an unfamiliar environment and accumulating the countless necessary new skills. In simple terms the brain puts these skills into practice by using two separate ‘channels’ to direct the movements and actions of the body: a cognitive channel involving conscious thought in the brain’s simple but fast ‘processor’, things like problem solving and decision making, and; a sub-conscious channel using complex movement sequences learned through repetition, like a golf swing or manually flying an aeroplane.

The trouble is that each of these channels is vulnerable. Human cognitive capability is finite and prone to overload in times of stress, it can be misled by confusing or contradictory inputs and it is very poor at recognizing its own errors. Learned skills on the other hand can be eroded by lack of practice, confounded by unfamiliar circumstances or initiated at an inappropriate time.

The increasing sophistication of aircraft computers in their ability to make calculations and to control the aircraft systems has had a fundamental effect on the role of the pilot, changing it from primarily controlling to mostly monitoring and observing. Unfortunately like all humans, pilots are prone to fatigue, distraction, boredom, complacency, illness and stress and each of these can impact significantly upon the prolonged concentration required to be an effective monitor – machines tend to be much more reliable and accurate.

Human/Machine Interface

The effective operation of aircraft and their systems requires there to be a point or points at which humans can interface with them, receiving the information generated, making decisions and responding with appropriate inputs and selections. Pilots work with the FMS through several physical and optical interfaces (even a few aural ones) including the flight controls, the cockpit displays, the CDU keyboard and the autopilot and flight director system controls, each of which is conceptually very different.

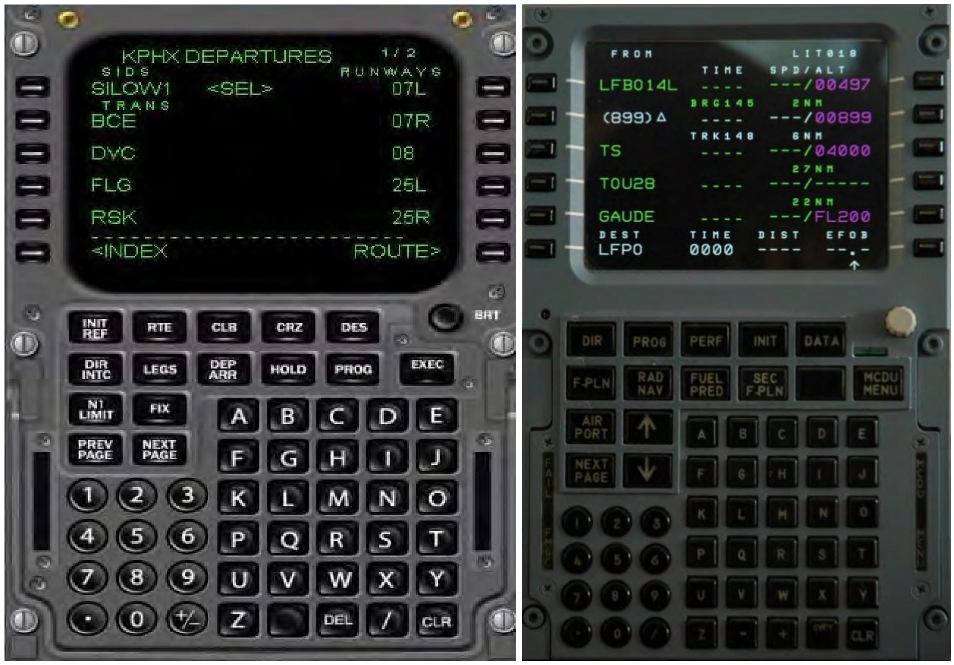

Figure 2: Typical FMS Control & Display Units (CDU)

To an experienced pilot the flight control interface is probably entirely intuitive but the same cannot necessarily be said for the others. With the exception of the very latest generation of aircraft, CDU keyboards have stuck with the original square alphabetical layout rather than the QWERTY layout most people will use elsewhere in their lives. The CDU display is simplistic, often using only one or two font colours and sizes on a series of discrete pages that pilots must select in turn. The autopilot and flight director system controls, located mostly but not exclusively on the cockpit glareshield, use unique combinations of rotating, pulling, pushing and switching to convey critical commands to the system, but the effect of each selection is generally displayed elsewhere on another instrument panel. The main cockpit displays use a variety of colours, fonts and symbols to combine a vast amount of data and information into a few small screens, requiring careful monitoring, scanning and interpretation by the pilots.

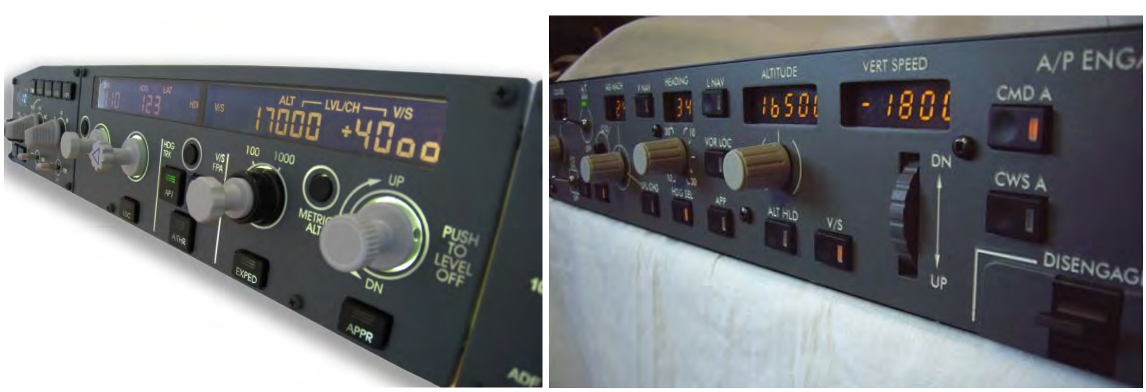

Figure 3: Typical Glareshield Autopilot/Flight Director Interfaces

Organizational Factors

Operators publish policies and develop procedures in order to shape the behavior of individuals within the organization but unless those individuals subscribe to the same beliefs as the policy-makers they are unlikely to conform entirely, especially when out of sight. This points to a definition of organizational culture as ‘the common behaviors and beliefs which define a group of individuals’ and it is vital to get it right to ensure that people do the right thing even when no-one else is looking. There will always be outlying individuals who do not fit in but if the majority accept and support the culture it can thrive and grow. Fairness, openness and consistency from management (sometimes referred to as a ‘just’ culture) will foster trust, compliance and professionalism within the team, essential to identifying threats, minimising errors and enhancing error management.

Organizations can introduce threats to the system, which make FMS data entry errors more likely, and they can provide tools which reduce the likelihood of errors or make it easier to detect and manage them once made. A common threat in commercial airline operations is time pressure, (whether it is actual or perceived), leading to stress, rushing, short cuts and errors. Human nature is such that an individual, when undertaking a repetitive task will try to introduce shortcuts. Understanding the purpose, the need for a process to address the risks will help to minimise the human desire to introduce ‘shortcuts’. Airline managers must carefully balance the commercial imperatives of on-time performance and cost control with an understanding of the consequent effects on human behavior. Fuel saving initiatives like taxiing on one engine can increase workload during a critical phase of operation and make errors more likely. Airlines may establish centralized functions like load control and take-off performance calculation, apparently reducing cockpit workload and distraction but at the same time increasing the amount of cross-checking required. Laptops and electronic flight bags may assist with complex data functions but introduce further opportunities for data entry, calculation and transcription errors.

Changes in the organizational environment also have the potential to become threats – rapid airline expansion requiring the influx of many new personnel and thereby diluting the prevailing culture; early promotions and direct entry commanders bringing relative unknowns to the cockpit; airline mergers and takeovers with conflicting cultures and procedures; restructuring and redundancies creating uncertainty and resentment. All of these threats need to be analysed, understood and managed to ensure that they don’t contribute unduly to errors in the cockpit.

Finally, operators have a responsibility to ensure that the service provider for their FMS databases can provide adequate assurance of the integrity and accuracy of the data, which must be accepted at face value by the pilots at the point of use.

Common Error Types and Best Practice Mitigations by Phase of Flight

Planning – errors in the data that pilots take onto the flight-deck with them, and ultimately enter into the FMS, can begin well before they board the aircraft:

TRAPS	MITIGATIONS
Mass & Balance – aircraft mass and balance data like aircraft basic weight and centre of gravity, whether it is stored on a database or recorded on paper, may be incorrect and will ultimately affect the zero fuel weight (ZFW) and ZFW centre of gravity (ZFWCG) entered in the FMS.	The operator's quality management system must include regular audits of the process by which these data are derived and the accuracy of the values themselves. All discrepancies should be reported via the safety management system (SMS) reporting program and addressed appropriately.
Flight Plan – the operational flight plan, which may be calculated manually by the pilots or more usually nowadays generated by flight planning software, may be incorrect and include erroneous information for take-off weight, fuel burn, route, winds and cost index.	Standard Operating Procedures (SOPs) must include appropriate cross-checks for all manually calculated flight planning data. SOPs must include appropriate gross error checks for all computer generated flight planning data. Pilots should check that the operational flight plan matches the ATC filed plan.
Load and Trim Sheet – aircraft loading that is contrary to the loading instruction or mistakes in calculations made by the load controller may introduce errors to data required for the FMS.	SOPs for load control must include appropriate gross error checks and cross-checks for loading data. The SMS reporting program must be non-punitive and encourage loading staff to report errors and discrepancies in loading. Education and training for loading staff will help spread an understanding of the importance of loading accuracy.
Navigation Database – latent errors may exist in the navigation database.	The contracted navigation database provider must be able to demonstrate the assurance processes it uses to ensure accuracy, and undertake to adhere to them. The operator's quality management program must include regular audits of database accuracy. SOPs must include a check of the navigation database currency before flight. All discrepancies should be reported via the SMS reporting program and addressed appropriately.

Pre-flight – the period between boarding the aircraft and engine start is when much of the critical data are calculated and most are entered into the FMS but it is also one of the busiest periods of the flight with conflicting demands on the pilots' time.

TRAPS	MITIGATIONS
FMS Limitations – FMS computer processing power is limited and can be overwhelmed. Earlier FMS do not incorporate internal automated cross-checks of data values.	Never make simultaneous entries on both multifunctional control display units (MCDUs) and ensure only one key is pressed at a time. Never make data entries when the FMS is processing a calculation. FMS entries should be slow and deliberate to ensure that they reflect the pilot's intention. Check that the scratchpad is blank/clear before commencing programing or preparing an entry. Check the aircraft position for initialisation against the prescribed data (aerodrome chart, airport sign or company data as appropriate). Scratchpad messages should be reviewed by both pilots to confirm the implications before being deleted. Pilots must have a good understanding of the FMS data entry and display conventions like: data pairs separated by a /; entry of positive and negative values; user defined waypoints.
Data Calculation – take-off performance and the associated thrust, speed and configuration data, is dependent on a significant number of variable inputs, the values of which are frequently not defined until close to departure, thereby compressing the time available for calculations. Typically the loadsheet with vital mass and balance data is not completed until 15 minutes before push-back and whilst the pilots may have made preliminary calculations based on estimated values these may change significantly requiring complete recalculation. It is also important that the environmental conditions used in the calculations are as close as possible to those prevailing at the time of take-off and especially in rapidly changing conditions pilots must use the very latest reports. Whether the calculations are made manually or by reference to a software application on a laptop or electronic flight bag (EFB) the pressure of time can lead to errors of calculation, omission of essential checks and the failure to identify erroneous data.	SOPs for the calculation of take-off data must take account of the time available and the possibility that a subsequent calculation may be required. Pilots must adhere rigorously to the calculation and cross-checking procedure and not be tempted to make short cuts. Perform the take-off data calculation and cross-check according to the SOP, ensuring that the latest runway environmental data are used and that the loadsheet values are correctly transcribed – the most robust safeguard against output error is for each pilot to make entirely separate calculations and then to compare results. If operating with an augmented or 'heavy' crew, consider using them to provide a further calculation and/or cross-check of the data but do not devolve the responsibility to them alone.

TRAPS	MITIGATIONS
	Where available use gross error checks from other systems to verify the accuracy of the take-off data (V_2 or minimum clean speed for example, which may be calculated separately by the FMS using the aircraft gross weight). SOPs must include defined limits for acceptable changes to data inputs (weight, fuel, index, wind etc) before a recalculation is required. Gross error checks should be developed for all critical data calculations. Adhere to the SOPs for task allocation of data entry and cross-checking, and whether to have one pilot read out the data while the other confirms from the source or for them to perform individual cross-checks.
Data Transcription – whether calculated manually or by software at some point the calculated values must be transcribed into the FMS and there is significant potential for errors in this mental and physical interface such as misreading the data, misunderstanding the data, inadvertently transposing values, entering incorrect values (see the Case Study above), entering data in the wrong field or omitting values entirely. Once again this is usually completed in the final few minutes before departure.	Pilots must be made aware of the potential for these transcription errors and be trained to rigorously adhere to SOPs for transcription and cross-checking. If inserting a route manually beware of duplicate waypoint/navaid identifiers and airways with more than one common intersection. If necessary to insert user defined waypoints (lat/long, place/bearing/distance, waypoint +/-, bearing/bearing etc) take care to verify that they are on the required route. Cross-check the route against the operational flight plan (and hence ATC plan), checking tracks and distances and using the horizontal display to highlight anomalies. Check the FMS departure and transition against the charts to confirm the route and any altitude or speed constraints – if available use the horizontal display to show the constraints. Always refer to the 3-letter identifiers for navigation aids rather than the geographical name of the aid to prevent confusion. When available check the loadsheet basic data for accuracy (registration, date, basic weight and index) and review the output values of mass and balance against those expected – investigate any significant differences.

TRAPS	MITIGATIONS
	Beware of common errors such as reversing or transposing digits or inserting values into the incorrect field. Cross-check the take-off data using displays such as the airspeed indicator for V speeds and N_1/Engine Pressure Ration (EPR) gauges for take-off thrust.
Cross-checking – however the data come to be in the FMS, by manual entry, direct from the FMS database or by uplink they must be cross-checked for accuracy and reasonableness. Pilots' procedures will direct them to cross-check most of the input and output data of the FMS during the pre-flight phase and almost every time they do it, the data will be accurate and correct. This laborious checking of routinely accurate data can lead to omissions, oversights and complacency. If an error is identified during pre-flight it will probably be necessary to recalculate the value or values in whatever time remains.	Pilots must be made aware and regularly reminded of the risks of complacency when cross-checking FMS data. Pilot proficiency assessments should include diligence in cross-checking data. Conduct individual cross-checks silently to avoid inadvertently passing on errors. The SMS reporting program must be non-punitive and encourage reporting of errors in cross-checking data in order to enhance awareness of the risk. Use the departure briefing to highlight critical items of FMS data as a further check and cross refer to other displays to confirm values where possible. Once the ATC clearance is received (radio or Pre-departure Clearance [PDC]) check that the FMS route conforms – amend and re-check if necessary.
Time-pressure – a great deal must be achieved in the pre-flight phase which is typically under one hour and sometimes much less than that, especially during a turnaround. The pilots must complete the external inspection, liaise with ground and cabin staff, review the aircraft maintenance status, make a number of data calculations, program and cross-check the FMS, prepare and conduct briefings and address the passengers. Time-pressure may lead to short cuts, omissions, errors and oversights in the calculation, entry and cross-checking of FMS data.	Pilot training should include strategies for time management and for coping with time pressure. Operators must make it clear that adherence to SOP takes precedence over departure time. Collaborative training for pilots, cabin crew and ground staff should emphasise the risks of time pressure. Any significant late changes to environmental conditions or to the aircraft loading (values as defined by SOPs) require that the take-off data be recalculated and re-checked in accordance with the full procedure. Where available use a second FMS route to insert the most likely option if the flight planned route cannot be followed – alternative take-off runway, engine out departure, immediate return to departure airfield, diversion – in order to minimise programing time in the event of a change.

TRAPS	MITIGATIONS
Distractions – there are multiple and often conflicting demands upon the pilots during the pre-flight phase and it is easy for them to be distracted from or during vital data related tasks. It is impractical to entirely cocoon the pilots because communication is vital but cockpit visits by cabin crew, load controllers, ramp agents and engineers, and radio and interphone communications with dispatch, ATC and ground staff all compete for the pilots' attention.	Collaborative training for pilots, cabin crew and ground staff should emphasise the risks of distraction. SOPs should be written to allow for 'modular' progress through pre-flight preparation. If distracted from a procedure or process, return to the start and begin again. Pilots should communicate to cabin crew and ground staff when they require to be left alone.

Start Up & Taxi – immediately prior to and during the taxi phase the pilots must develop and maintain a robust situational awareness of the ground environment in order to avoid conflictions, collisions and incursions but at the same time changes in the weather or ATC instructions may require the recalculation and re-entry of FMS data.

TRAPS	MITIGATIONS
Weather – significant changes in the prevailing weather, including wind strength and direction, precipitation and temperature may require the FMS data to be revised.	Any significant changes to environmental conditions require the take-off data to be recalculated and cross-checked according to the SOP – it may well be necessary to stop the aircraft in order to achieve this safely and accurately.
Runway – late changes to the runway in use, the runway condition or departure intersection may likewise require the data to be amended.	Any significant runway changes require the take-off data to be recalculated and cross-checked according to the SOP – it may well be necessary to stop the aircraft in order to achieve this safely and accurately.
Departure – ATC may advise changes to the departure to be flown after take-off and this too will require the pilots to update the FMS data.	A change to the ATC clearance may require the route to be amended and cross-checked according to the SOP – it may be necessary to stop the aircraft.
Conflicting Demands – during taxi the pilots communicate with ATC, cabin crew and possibly dispatch, they navigate and guide the aircraft along the cleared taxi route, select and cross-check flap/slat configurations, review the FMS and other displayed data, conduct any final take-off briefings and complete one or more checklists. Any requirement to recalculate and re-enter FMS data will likely conflict with these tasks creating the potential for errors, omissions and oversights in the data. The additional attention required to ensure FMS data accuracy may conversely lead to errors in	SOPs must define a point prior to engine start, typically closure of the last external door, from which the sterile cockpit procedure prevails and this should continue until at least 10,000 feet in the climb – during this time there should be no visits to the cockpit, minimal communications from the cabin crew and no non-operational conversation by the pilots. From shortly prior to brake release until the aircraft is parked at destination one pilot must be primarily engaged with managing the aircraft at all times – SOPs must be clear on the allocation of this role.

the taxi route, possibly contributing to a mismatch between the calculated data and the actual aircraft take-off position (erroneous departure from the wrong intersection).	Flap/slat selection is often made after engine start and must be checked against the calculated take-off data inserted into the FMS. The take-off briefing or review should be used as another opportunity to confirm and check critical FMS data and cross-check with other displays such as stabiliser/trim setting, thrust setting, flap/slat configuration and V speeds. Approaching the runway verify that the intersection to be used for take-off corresponds to that used for the take-off data calculation and to the FMS.

Take-off and Initial Climb – very few FMS data entries or cross-checks are made during these phases but it is during take-off that many of the most serious implications of data entry errors will become apparent.

TRAPS	MITIGATIONS
Weight – if the actual take-off weight differs significantly from the weight used to calculate the take-off data entered in the FMS, then much of that data will be incorrect, including the thrust setting, V-speeds and possibly flap/slat configuration.	Pilots must be alert to aircraft performance anomalies related to potential FMS data entry errors and be prepared to react promptly – early in the take-off roll the safest option is to stop. Performance deficiencies detected later in the take-off are more difficult to manage and pilots will need to use their judgement – if the decision is to 'go' then full power must be applied immediately to expedite the take-off.
Balance – incorrect aircraft balance data will have generated an inappropriate horizontal stabiliser or trim setting for take-off, potentially creating aircraft control problems at rotation.	Pilots must be prepared to quickly and positively correct their control inputs to manage any control difficulties during rotation and initial climb. Simulator training should if possible include take-off trim anomalies.
Thrust – excess thrust is unlikely to have any adverse impact on take-off but insufficient thrust will erode accelerate/stop distance margins and may ultimately lead to runway overrun (see Case Study above).	Pilots must be alert to aircraft performance anomalies related to potential FMS data entry errors and be prepared to react promptly – early in the take-off roll the safest option is to stop. Performance deficiencies detected later in the take-off are more difficult to manage and pilots will need to use their judgement – if the decision is to 'go' then full power must be applied immediately to expedite the take-off.

TRAPS	MITIGATIONS
Speeds – incorrect V-speeds may contribute to aircraft control difficulties, runway excursion, tailstrike or inappropriate stop/go decision making in an emergency.	Performance deficiencies detected later in the take-off are more difficult to manage and pilots will need to use their judgement – if the decision is to 'go' then full power must be applied immediately to expedite the take-off.
Configuration – selecting the wrong flap/slat configuration for take-off may adversely affect aircraft performance during rotation, lift-off and initial climb.	Any activation of a configuration warning at thrust setting must result in the take-off being abandoned and the cause investigated.
Departure Route – errors in the departure route entered in the FMS may contribute to loss of separation from other traffic, airspace incursion or unsafe terrain proximity after take-off.	Aircraft trajectory once airborne must be monitored carefully to ensure that the lateral and vertical clearances are adhered to – any deviation must be corrected immediately using inputs to the autopilot/flight director system if required to avoid risk of loss of separation or terrain proximity. Whilst airborne pilots must adhere to the SOP task allocation for autopilot/flight director system selections.

Climb and Cruise – once airborne navigational data in the FMS becomes as important as aircraft performance data and errors in FMS entries can be critical.

TRAPS	MITIGATIONS
Route – the route entered by manual entry, via uplink or from the database drives the predictions of flight time and fuel generated by the FMS and if incorrect these may inappropriately affect operational decisions made by the pilots. If the FMS route does not correspond to the filed flight plan there may be airspace incursions, terrain proximity and traffic conflictions and the same may be true in the case of erroneous FMS route amendments made during flight (see Case Study above).	Changes to the ATC clearance should be confirmed by both pilots before being inserted into the active FMS route. Amendments to the FMS, whether by manual entry, database selection or uplink must always be verified by both pilots in accordance with SOP before they are inserted or executed – this includes a check of the other displays as appropriate (horizontal display of proposed new route for example). Use FMS predictions of time and fuel at destination to identify gross errors especially after route amendments – any significant change in these values must be investigated. Pilots must fully understand route modification strategies such as 'direct to', intercepting radials and airways, user defined waypoints and 'offsets' and be alert to route discontinuities after route amendments.

TRAPS	MITIGATIONS
	Long ‘direct to’ legs may remove waypoints from the route that would have been used for fuel progress checks – select or insert ‘on track’ or ‘abeam’ waypoints if available to replace them. Prior to each waypoint check track and distance to the next waypoint against the operational flight plan – if the route has been amended calculate approximate values to perform the check. Use abeam points, second FMS routes and appropriate screen displays to mark suitable *en route* diversions. FMS route data accuracy is especially important when flying over remote and oceanic regions, where there are no other navigational aids for cross-reference. Even in cruise there should be no occasions when both pilots are engaged ‘head down’ with the FMS at the same time – one should make the selections and the other cross-check prior to insertion.
Weight – an incorrect aircraft weight value will also affect FMS predictions and the calculation of maximum and optimum altitudes, although some aircraft can correct this once airborne.	Throughout the flight regular checks of the FMS predicted time and fuel at destination should be made – they should remain consistent unless there has been a significant change in the FMS, the cruise level, the wind or crucially the fuel state.
Environmental Data – as with the aircraft weight, if the winds and temperatures entered or uplinked are not accurate many of the predictions and calculations will be incorrect.	Throughout the flight regular checks of the FMS predicted time and fuel at destination should be made – they should remain consistent unless there has been a significant change in the FMS, the cruise level, the wind or crucially the fuel state. Update winds and temperatures manually or by uplink as necessary.

Descent – towards the end of the flight and in particular during descent the FMS fuel and time predictions become more critical to pilot decision making and any incorrect data may impact upon this process.

TRAPS	MITIGATIONS
Top of Descent – if the weight, route or other data entered in the FMS are incorrect then calculation of the descent path and consequently top of descent point will be affected. This may lead to high rates of descent, time compression and possible terrain proximity and may contribute to a subsequent unstable approach.	Pilot flying should hand over control to the other pilot in order to program the FMS and take back control for the other pilot to cross-check the FMS. Beware of duplicate names of navigation aids and cross-check before selecting. Enter and/or cross-check the descent winds in the FMS. Check FMS top-of-descent point and altitude/distance relationship for descent in the forecast wind conditions. If available program the second FMS route for the next most likely approach/runway to reduce potential re-programing in descent. Conduct the arrival briefing well before top-of-descent (10 minutes at least) and use the briefing as an opportunity to highlight and cross-check critical FMS data using all appropriate displays.
Landing Performance – landing performance calculations based upon FMS predictions may be incorrect.	Obtain destination and alternate weather, and runway in use (ATIS) whilst in cruise. Use the FMS prediction for fuel at destination plus zero fuel weight to calculate landing weight and determine landing distance required in the forecast/reported conditions.
Fuel – incorrect FMS data may cause inaccurate fuel predictions and affect operational decisions related to holding or diversion.	Monitor arrival fuel prediction throughout descent. Program the route to the selected alternate, including most likely arrival, approach and runway for the most accurate fuel prediction.
Route – as well as affecting FMS predictions, an incorrectly entered route for descent may take the aircraft into restricted airspace or close to terrain.	Check the navigation accuracy status. Enter the expected arrival (including holding), approach and runway in the FMS. Check the chart for altitude/speed constraints and confirm in the FMS using displays as appropriate. In descent monitor vertical deviation from the FMS calculated path together with altitude against distance to touchdown, in relation to altitude/speed constraints and aircraft energy management.

TRAPS	MITIGATIONS
ATC – it is not unusual for ATC to amend route and altitude instructions during the descent and accommodating these changes in the FMS requires the pilots to divide their attention between operating and monitoring the aircraft, and FMS data entry/cross-checking.	Be prepared for ATC clearance changes – cross-check before inserting and consider/brief the implications. Avoid lengthy or complex FMS programing below 10,000 feet where possible.

Arrival, Approach and Landing – these are very busy phases of the flight and all of the considerations applicable to descent are even more relevant as available time, fuel and altitude diminish.

TRAPS	MITIGATIONS
ATC – ATC may well instruct changes to the arrival, approach and runway in use, which could render the FMS data incorrect.	If holding is required confirm the orientation and direction of the holding pattern in the FMS with the chart or with ATC before entry. Reduce to the correct holding airspeed prior to entering the hold and monitor the FMS hold entry for accuracy – if necessary intervene with autopilot/flight director system selections. Monitor fuel in the hold and calculate latest exit time/fuel in relation to any estimated approach time (EAT). When cleared for the approach, ensure correct waypoint sequencing to maintain accurate predictions and FMS flight phase. Do not engage in major FMS re-programing – if necessary use autopilot/flight director system selections instead but be aware that FMS predictions may no longer be accurate.
Weather – unexpected changes in surface conditions and runway state may also be at odds with the respective data in the FMS.	Monitor Automatic Terminal Information Service (ATIS), ATC and pilot reports for significant changes to environmental conditions – it may be necessary to request additional track miles to make changes to the FMS.
Approach & Landing Performance – the speeds for approach and landing and the selected flap setting may be incorrectly entered in the FMS leading to inappropriate approach and landing performance and potentially an unstabilized approach and/or runway excursion.	Be alert to unusual aircraft performance, steep or fast approach and correct as appropriate – if necessary go-around. Observe the stabilized approach criteria. In the event of a go-around ensure the correct waypoint sequencing for the missed approach path, second approach or route to the alternate.

TRAPS	MITIGATIONS
Conflicting Demands – as the workload increases towards landing and the time to make FMS changes diminishes the pilots must decide which FMS data amendments are critical to the flight and which may be safely disregarded in favor of flying the aircraft.	SOPs must define a point, typically 20,000 feet or top-of-descent, from which the sterile cockpit procedure applies (see Pre-Flight above) and continues to apply until the aircraft is parked – during this time there should be no visits to the cockpit, minimal communications from the cabin crew and no non-operational conversation by the pilots.

Strategic Error Prevention and Management

Procedures – in general the standard operating procedures promulgated to pilots should reflect the procedures published by the aircraft or system manufacturer. If these are found to be impractical or ineffective then the operator should first attempt to resolve the situation in partnership with the manufacturer and only as a last resort develop their own unique procedures. The adoption of common procedures throughout the global user-group offers the best opportunity to identify and rectify shortcomings to achieve the best possible operating procedures. In all cases the procedures must be: robust, in that that they achieve the desired outcome in all circumstances; logical, in that the process makes sense to the user in the context of the overall task, and; modular, in that individual task processes can be completed separately from others to allow for unforeseen interruptions and distractions. However, none of this can be effective without a universal culture of procedural compliance within the pilot group, supported and fostered by training and airline management.

Monitoring and cross-checking – constant monitoring and repetitive cross-checking are vital to the identification and management of all errors, including those of FMS data entry. Unfortunately humans are not especially good at either function, being prone to boredom, complacency, distraction and fatigue. Where alternative technological solutions (see below) are not available it is essential that pilots recognize both the need for accurate monitoring and cross-checking and the inherent human weaknesses in these functions. Training must help them to build strategies to counter this threat, like periodically swapping tasks between entering and cross-checking data, developing gross error checks and rules of thumb (see below), building a mental picture of the ‘normal’ parameters for each phase of flight and recognizing the onset of symptoms of fatigue, stress and illness.

Time management – key to countering the threat of time pressure is effective time management. Pilot training and procedures must encourage them to plan ahead both strategically for the entire flight (or duty) and tactically for the current and next phases of the flight. At the same time they must be alert to changes in the operational environment and be prepared to amend or even abandon their original plan if appropriate. Decisions should not be rushed unduly but pilots must also recognize when the time for discussion and consideration has passed and a decision has to be made. They must be prepared to differentiate when necessary between safety critical operational time pressure and commercial time pressure, and respond accordingly. Operators need to be aware of the potential threat of organizational time pressure, whether it is actual or perceived.

Workload management – workload is a critical factor in threat and error management. Cockpit workload rises and falls with and during phases of flight, and pilots' training and procedures should encourage and enable them to utilize the periods of lower workload for routine tasks like reviewing the FMS, while confining activity to essential operational tasks during periods of higher workload. Significant workload management threats are distractions and interruptions, frequently from external sources such as the radio or cockpit visits. Whilst operational communications are unavoidable, strict adherence to sterile cockpit procedures during the critical phases of flight can reduce the threat and hence the risk of error. Collaborative training and procedures for pilots, cabin crew and ground staff can help to manage interruptions, especially common during the busy pre-flight phase. Fatigue is a major threat to individual workload capacity and an effective fatigue risk management system (FRMS) can help manage and mitigate the impact of fatigue.

Another significant workload management factor in FMS data entry errors is the allocation of FMS and autopilot/flight director systems selections to each pilot. Whilst parked at the gate the pilots can safely work together on the data entry and cross-checking processes but once the aircraft is in motion it is essential that one pilot is always primarily engaged with managing the aircraft. At critical phases of flight or periods of high aircraft management workload it may not be appropriate for either pilot to be involved with FMS programing at all. In the pre-flight phase it makes sense for the pilot nominated to 'fly' the aircraft (generally known as the pilot flying) to enter the majority of the data and especially the flight plan, while the other pilot (variously referred to as pilot monitoring, pilot not flying or non-handling pilot) performs the monitoring and cross-checking functions. However, at other times this may no longer be optimal in terms of error prevention and the allocation of tasks at these times must be clearly delineated in the procedures. SOPs and pilot training must have clear direction as to which pilot is to make selections which will affect the aircraft trajectory at specified phases of flight. In manual flight the pilot flying should command all selections and the other pilot should perform them. In automatic flight it is more appropriate for the pilot flying to command selections at lower altitudes (generally below 10,000 feet) or at times of high workload but to make selections themselves in cruise and low workload periods. In all cases the output of any selection must be confirmed by both pilots reading from the flight mode annunciations or the display screens as appropriate. In general, the FMS CDU should be regarded as the pilot interface for long term strategic interventions and the autopilot/flight director system controls on the glare shield (mode control panel or flight control unit) as the interface for short term tactical interventions, keeping the pilot's attention more 'head up'.

Gross error checks – the range of variables in some parameters affecting aircraft performance data can be so great that it would not be possible for pilots to know precisely what to expect in every circumstance. However, it is possible to develop ‘rules of thumb’ and gross error checks for many of the values that are input to and output by the FMS on a given aircraft type. Rigorous application of these checks offers an additional opportunity to identify errors which may have slipped through the procedural defences. Knowing roughly what to expect from a calculation before it is executed, or what performance parameters an aircraft is likely to exhibit will help pilots to recognize potential data anomalies. Operators should discuss potential gross error checks with manufacturers and fellow operators so that the global fleet can benefit from identified best practices.

Professionalism – a professional will accept that in almost all situations the most assured route to the desired outcome is to follow the correct and entire procedure, without short cuts, omissions or ‘work arounds’ and professionalism is a reflection of this acceptance. The control and management of FMS data entry errors requires the utmost professionalism from all those involved, adhering to procedures and being alert to threats. The culture within an organization must support and promote professionalism amongst all safety critical staff.

Mutual mistrust – mutual mistrust is a condition in which individuals harbor a healthy degree of doubt with regard to the actions of their colleagues. Clearly, a pervasive air of genuine mistrust would not be conducive to good crew resource management but a professionally questioning approach that does not automatically accept information, actions and decisions as correct can help to manage threats and to identify errors. The same would be true with regard to an individual’s own activities, never accepting that the right action has been taken without verifying the outcome and eliminating any doubt. Without perhaps being aware of this specific term, pilots regularly demonstrate a degree of mutual mistrust when cross-checking each other’s actions in accordance with their SOPs.

Education and awareness – all of the foregoing strategies rely upon robust and comprehensive training to instill and encourage behaviors which are known to help avoid, identify and manage data entry errors. It is vital that the training accurately reflects the operational reality and helps pilots to understand the threats they face at work. Training must focus on producing consistent and standardized pilot behaviors across the fleet. Due to time constraints and syllabus requirements simulator training can induce undesirable behaviors like the rapid cancelling of multiple FMS scratchpad messages during repositioning and it is vital that this is minimized in session plans. Familiarity with FMS operating principles and conventions comes with use and regular access to dedicated FMS trainers offers a cost-effective avenue to increasing pilots’ knowledge, skills and awareness and to identifying common errors.

Technology – as mentioned above there are some functions which machines perform rather better than humans, including monitoring and cross-checking. Increasingly aircraft systems, including the FMS, are being designed to incorporate internal safeguards and checks to ensure that potentially erroneous values are highlighted to the pilots immediately, requiring them to be checked before proceeding. The FMS should also be able to highlight to the pilots if its own navigation database is out of date rather than expecting them to check it before each flight. These eminently reliable technological solutions are probably the best final line of defence against hazardous FMS data entry errors. Other possible technological enhancements include the use of a greater variety of colors and fonts on the CDU screens, and the use of QWERTY layout data entry keyboards. Perhaps most effective of all in managing errors would be the reconfiguration of all of the controls and indications for the integrated FMS to ensure that the operating philosophies are consistent and intuitive, and the relevant displays are located adjacent to the controls. FMS navigation databases contain numerous duplicate names for navigation aids and for waypoints, which offer significant potential for error (see Case Study above). Whilst the solution to this is not solely technological it would remove a potential error source from within the FMS itself.

Conclusion

In its latest incarnations the FMS is a sophisticated system integrated into virtually every function of the aircraft, providing the pilots with their primary aircraft control interface for the majority of each flight. It has taken on so much workload that only the two pilots remain as essential crew in the cockpit. There is no doubt that the FMS has revolutionized the task of operating an aircraft, offering efficiencies and accuracies that were never before available. However, the FMS has also introduced threats and the potential for errors, which can have catastrophic implications for the safety of flight. It has also fundamentally changed the tasks of the pilots to an extent which may even be counter-productive.

For the foreseeable future all commercial air transport aircraft will be delivered with an FMS installed and so operators and pilots must ensure that they are adequately prepared for the threats and fully aware of the potential for errors associated with managing the aircraft through the FMS. Until the FMS is able to identify erroneous input and output data in all cases, it will fall to the pilots to perform this vital function and the old saying of ‘rubbish in, rubbish out’ will remain true. There are many things that pilots, operators and manufacturers can do to reduce the threats and manage the errors associated with operating the FMS, some simple and some more complex, but the foregoing should provide guidance for maintaining or improving standards of safety across the industry.