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Safety behaviours: human factors for pilots 2nd edition

Resource booklet 8 Threat and error management

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The threat and error management (TEM) concept, developed at the University of Texas in the late 1990s, looks at how airline flight crew respond to external threats and internal errors that could lead to undesired aircraft states during flight.

The TEM model can be used to analyse a single event, or to understand systemic patterns within a large set of events. It can also be used to help clarify human performance needs, strengths and vulnerabilities, and as a training tool to help an organisation improve the effectiveness of its training interventions, and consequently its organisational safeguards.

Contents

People cannot easily avoid those actions they did not intend to commit.

James Reason

Introduction

Threat and error management (TEM) is a safety management approach which has been described as 'simply an extension of the concept of airmanship.'[2]

It is the process of detecting and responding to threats (such as adverse weather) and errors (such as unclear communication between crew members) before they compromise safety. TEM aims to maintain safety margins by training pilots and flight crews to detect and respond to threats and errors that are part of everyday operations.

If not properly managed, these threats and errors have the potential to generate *undesired aircraft states* (UAS). The management of undesired aircraft states represents the last opportunity to avoid an unsafe outcome and thus to maintain safety margins in flight operations.

The International Civil Aviation Organization (ICAO) acknowledges TEM as a critical foundation of all pilot training regardless of the size or scope of the operation.

In line with ICAO's support for TEM, CASA published CAAP 5.59-1 in 2008, with key TEM principles.[3] In 2009 CASA also incorporated TEM into the recreational pilot licence (RPL), private pilot licence (PPL), commercial pilot licence (CPL) and air transport pilot licence (ATPL) as a formal assessment requirement.

This booklet looks at applying TEM to single-pilot and multi-crew charter operations.

What is TEM?

TEM provides a way for pilots to look for potential threats to flight operations in a structured way. They actively manage these threats and any errors that may lead to undesired aircraft states and therefore to the safety of the flight. TEM encompasses training, briefings, checklists, standard operating procedures, and human factors principles for single-pilot and multi-crew operations.

Threat and error management

- Recognise and manage errors
- Recognise and manage threats
- Recognise and manage undesired aircraft states

TEM involves:

- planning to identify threats and errors during a flight and implementing countermeasures to eliminate or minimise them
- directing actions to address threats and errors, using checklists, approved procedures, and other acceptable means, including self-direction during single-pilot operations
- controlling the progress of events to ensure a safe outcome. This step requires monitoring progress and amending plans and actions as required, including correcting any undesired aircraft state (UAS).

TEM and risk management

TEM *complements* risk management, which is the process of deciding whether operations can be safely conducted to an acceptable level of risk, and which includes go/no-go or divert decisions. TEM applies to managing and maintaining safety during a flight.

Let's have a look at its core components of threats, errors and undesired aircraft states.

Threats

CASA defines a threat as a situation or event that has the potential to have a negative effect on flight safety, or any influence that promotes an opportunity for pilot error/s.

Threats are generally external (such as bad weather) or internal (such as physiological and psychological state).

Threats such as fatigue increase the likelihood of errors, leading to degraded situational awareness and poor decision making. Pilots need good situational awareness to anticipate, recognise and manage threats as they occur.

For charter operations, *external* threats include:

- adverse weather
- weight and balance
- passenger distraction
- early starts and late finishes
- night operations
- reduced runway length
- other traffic, high terrain or obstacles
- the condition of the aircraft.

Typical *internal* threats to charter operations include:

- fatigue
- inexperience
- over-or under-confidence
- isolation
- impulsiveness
- lack of recency and proficiency
- press-on-itis.

External threats	Examples
Adverse weather	Thunderstorms, turbulence, poor visibility, wind shear, icing conditions, IMC
Aircraft	Systems, engines, flight controls, instruments
Airport	Poor signage, faint markings, runway/taxiway closures, poor braking action, contaminated runways/taxiways, condition of runway/taxiway
ATC	Tough-to-meet clearances/restrictions, reroutes, controller errors
Cabin	Cabin events, (flight attendant errors), distractions, interruptions
Dispatch/paperwork	Load-sheet errors, crew scheduling events, late paperwork, changes or errors
Environmental operational pressure	Terrain, traffic, radio congestion
Ground maintenance	Aircraft repairs on ground, maintenance log problems, maintenance errors
Ground/ramp	Aircraft loading events, fuelling errors, improper ground support
Manuals/charts	Missing information or documentation errors
Time pressure	Delays, late arriving passengers, cargo or refueller

Managing threats

The TEM model includes three threat categories: *anticipated*, *unanticipated* and *latent*. All three can reduce safety margins.

Latent threats may not be clear and may need to be uncovered by formal safety analysis and specifically addressed in your organisation's training and procedures.

ANTICIPATED

Some threats can be anticipated such as:

- thunderstorms, icing, wind shear and other forecast bad weather
- congested airports and landing areas
- wires and other obstacles
- complex ATC clearances
- cross and/or downwind approaches and landings
- outside air temperature/density altitude extremes
- aircraft mass and balance
- forecast or known bird/wildlife activity.

UNANTICIPATED

These are other threats that can occur unexpectedly, suddenly and without warning. Pilots must apply the skills and knowledge they have acquired through training and operational experience to deal with issues such as:

- in-flight aircraft malfunctions
- automation—anomalies and over-reliance
- unforecast weather, turbulence, icing

- ATC re-routing, unexpected congestion, non-standard phraseology, navigation aid unserviceability, confusion over similar call-signs
- ground handling
- wires and other obstacles
- unmanned aircraft systems (drones)
- unforecast bird/wildlife activity
- laser attacks
- contaminated or sloping landing areas.

LATENT

Some threats may not be directly obvious to, or observable by, pilots and may need to be discovered through formal safety analysis. These are considered latent threats and may include organisational weaknesses and the psychological and physiological state of the pilot. They include:

- organisational culture
- organisational change
- incorrect or incomplete documentation, such as poor manuals
- equipment design issues such as landing gear and flap levers located too close to each other, or inaccurate fuel gauges
- operational pressures and delays, such as undue pressure to get a job done
- perceptual illusions such as approaches to sloping runways
- fatigue and rostering
- lack of recent experience and proficiency
- stress
- over-confidence or under-confidence.

As we learn and gain experience we are better able to predict where threats may occur. Obtaining and interpreting a weather report allows us to prepare for bad weather, while experience helps us to understand our capabilities and limitations.

Regardless of whether threats are anticipated, unanticipated, or latent, a measure of a pilot's ability to manage threats is whether they are detected in time to avoid an undesired aircraft state.

Errors

As humans we all make errors. In TEM, errors are defined as flight crew actions or inactions which lead to:

- a deviation from crew or organisational intentions or expectations
- reduced safety margins
- increased probability of adverse operational events on the ground and during flight.

Adverse operational events can be handling errors, procedural errors or communications errors.

Errors can be the result of momentary diversion of attention (slip), or memory failure (lapse) induced by an expected or unexpected threat. There are also more deliberate, *intentional non-compliance* errors. These are often shortcuts used to increase operational efficiency, but in violation of standard operating procedures.

Slips and lapses are failures in the execution of an intended action. Slips are actions that do not go as planned, while lapses are memory failures. For example, pulling the mixture instead of the carburettor heat is a slip. Forgetting to apply the carburettor heat is a lapse.

Mistakes are failures in the plan of action; even if execution of the plan was correct, it would not have been possible to achieve the intended outcome.

While errors may be inevitable, we need to identify and manage them before safety margins are compromised. Typical errors in charter operations include:

- incorrect performance calculations (mistakes)
- inaccurate flight and fuel planning (slips, lapses)
- non-standard communication (mistakes, violations)
- aircraft mishandling (slips)
- incorrect systems operation or management (slips, lapses, mistakes)
- checklist errors (slips, lapses)
- failure to meet flight standards, such as poor airspeed control (slips).

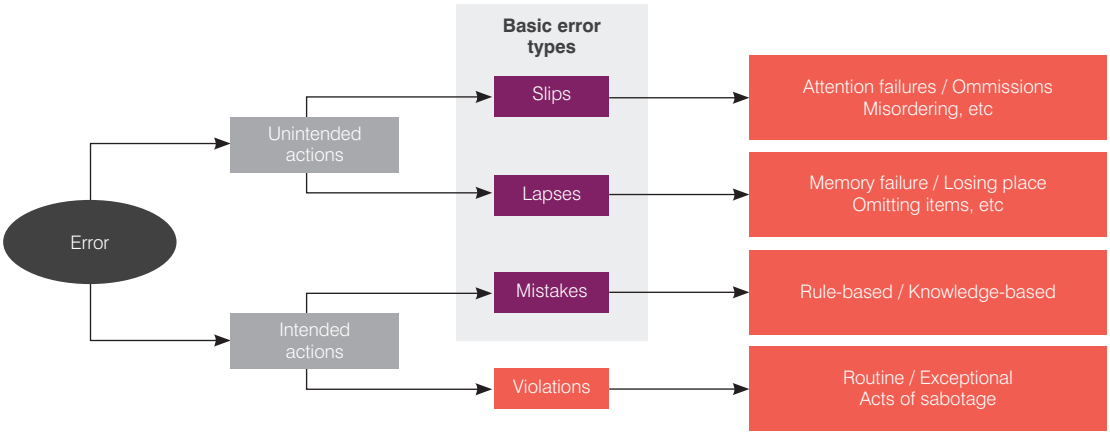

Figure 1 Basic error types

From Reason, 1991

Table 3 Examples of error types

Aircraft handling errors	Examples
Flight control	Incorrect flaps or power settings
Ground navigation	Attempting to turn down wrong taxiway/runway, missed taxiway/runway/gate, failure to hold short
Manual flying	Hand flying vertical, lateral, or speed deviations
Systems/radio/instruments	Incorrect GPS, altimeter, fuel switch, transponder or radio frequency settings
Procedural errors	**Examples**
Briefings	Missed items in the brief, omitted departure, take-off, approach, or handover briefing
Callouts	Omitted take-off, descent, or approach callouts
Checklist	Performed checklist from memory or omitted checklist, missed items, performed late or at wrong time
Documentation	Wrong weight and balance, fuel information, ATIS, or clearance recorded, misinterpreted items on paperwork
Other procedural	Other deviations from regulations, flight manual requirements or standard operating procedures
Communication errors	**Examples**
Pilot to external	Missed calls, misinterpretation of instructions, or incorrect read-backs to ATC, wrong clearance, taxiway, gate or runway communicated
Pilot to pilot	Internal crew miscommunication or misinterpretation

The aim of error management is to have pilots detect errors and respond quickly to them, so that the errors become operationally inconsequential and the risk to safety is minimised.

A mismanaged error is one which is linked to or induces an additional error or undesired aircraft state.

Undesired aircraft states

Undesired aircraft states (UAS) are pilot-induced aircraft position or speed deviations, misapplications of flight controls, or incorrect systems configurations associated with a reduced margin of safety.

For safe flight we must quickly recognise and recover from an undesired aircraft state before it leads to a loss of control or uncontrolled flight into terrain.

Examples of errors and associated undesired aircraft states in charter operations include:

- mismanagement of aircraft systems (error), resulting in aircraft anti-ice not turned on during icing conditions (state)
- inappropriate scan of aircraft instruments (error), resulting in an unusual aircraft attitude (state)
- flying a final approach below appropriate threshold speed (error), resulting in excessive deviations from specified performance (state).

Table 4 Examples of undesired aircraft states

Undesired aircraft state	Examples
Aircraft handling	Vertical, lateral or speed deviations
	Unnecessary weather penetration
	Unstable approach
	Long, floated, firm or off-centreline landings
Ground navigation	Runway/taxiway incursions
	Wrong taxiway, ramp, gate, or hold spot
	Taxi above speed limit
Incorrect aircraft configuration	Automation, engine, flight control, systems, or weight/balance events

Applying TEM and countermeasures

Threats and errors occur during every flight. Data from airline operations suggests that nearly half of flight-crew errors are not detected or responded to.[4] It is very likely that this will be no better for charter operations.

TEM involves anticipating and calling out potential threats and errors as well as planning countermeasures in the self-briefing process at each stage of flight to prevent threats and errors becoming an undesired aircraft state. This needs to be done in a structured and simple way, without becoming complacent about commonly-encountered threats such as weather, traffic, and terrain.

There are three kinds of countermeasures:

- **Planning** countermeasures including flight planning, briefing, and contingency planning.
- **Execution** countermeasures including monitoring, cross-checking, workload and systems management.

- **Review** countermeasures including evaluating and modifying plans as the flight proceeds, and enquiry and assertiveness to identify and address issues in a timely way.

Once you recognise an undesired aircraft state, you must use the correct countermeasure rather than fixate on the error.

So how do we do this in practice?

Your **preparation** for every flight, including interpreting NOTAMs and meteorological information, and checking fuel, should consider which actions, conditions or events are likely to promote errors and potential threats, and the appropriate countermeasures. An example is the action you propose if there are unpredicted weather changes.

Identifying threats can reduce your in-flight workload, as you have already prepared yourself to deal with them.

In-flight briefings (self-brief, crew and passengers) should include planned procedures, anticipated threats and countermeasures before take-off and commencing any significant flight sequence (such as an approach to an unfamiliar airport).

During flight you should:

- continuously monitor and cross-check visual and instrument indications and aircraft energy state to maintain situational awareness
- prioritise tasks and manage workload to avoid being overloaded, and to maintain situational awareness
- identify and manage threats and errors
- when confronted by threats and/or errors, configure the aircraft to make it as easy as possible to maintain control, including setting the correct flight path
- monitor the progress of every sequence and abort if necessary
- not fixate on threat or error management to the detriment of aircraft control
- identify and manage any undesired aircraft state
- return to planned flight and normal safety margins before dealing with other problems.

Post flight you should take a few minutes to go over any threats, errors and/or undesired aircraft states you encountered during the flight. Ask yourself how well they were managed and what you could do differently to improve their management. Note these and discuss them with your fellow pilots to develop improved TEM strategies for next time.

TEM in the charter environment

The TEM model distinguishes between environmental and organisational threats.

Environmental threats are beyond the control of the aircraft operator; the pilot must manage these in the time available. Examples of environmental threats in charter operations include:

- weather, such as turbulence, ice, wind, fog, storms, driving rain
- aerodrome conditions, such as congestion, complex surface navigation, poor signage/markings, and unprepared landing strips
- air traffic control issues, such as non-standard phraseology and complex clearances
- terrain, such as mountains, valleys and built-up areas.

Organisational threats, which are often latent, can be controlled by the operator or reduced through safety management systems, fatigue risk management systems, standard operating procedures, checklists, ground handling support and operational health and safety procedures. However, as the pilot you tend to be the last line of defence.

Examples of organisational threats in charter operations include:

- pressures such as tight turn-around times
- poor aircraft serviceability
- maintenance errors
- incorrect documentation such as incorrect or expired charts, an incomplete or erroneous maintenance release, or inaccurate fuel logs.

Error management

By acknowledging that errors will occur, we change our focus from error *prevention* to error *recognition* and *management*. Because unmanaged or mismanaged errors may result in an undesired aircraft state we need to be constantly alert to recognise and fix them early.

Once you recognise an error, it is important you focus on managing any resulting undesired aircraft state. In trying to manage an error, we can become fixated on its cause and forget firstly to 'aviate, navigate and communicate'.

For example, if you become uncertain of your position, you need to make a timely decision to perform a 'lost procedure'. You may be tempted to ascertain why you became lost and blunder on regardless (undesired aircraft state), rather than initiating a logical procedure to re-establish your position, seek assistance from other aircraft or ATC or plan a precautionary landing.

An effective tool for a post-flight TEM debrief is to use a simple timeline with the following steps:

Threat (T)

- **Pilot response (R)**
- **Outcome (O)** Inconsequential or consequential? Inconsequential means that there was no adverse outcome, i.e. there was no error.

Error (E)

- **Pilot response (R)**
- **Outcome (O)** Inconsequential or consequential? This time a consequential outcome may be a further error, or an undesired state.

Undesired Aircraft State (U)

- **Pilot response (R)**
- **Outcome (O)** Inconsequential or consequential? Again, a consequential outcome may be a further error, or an undesired state.

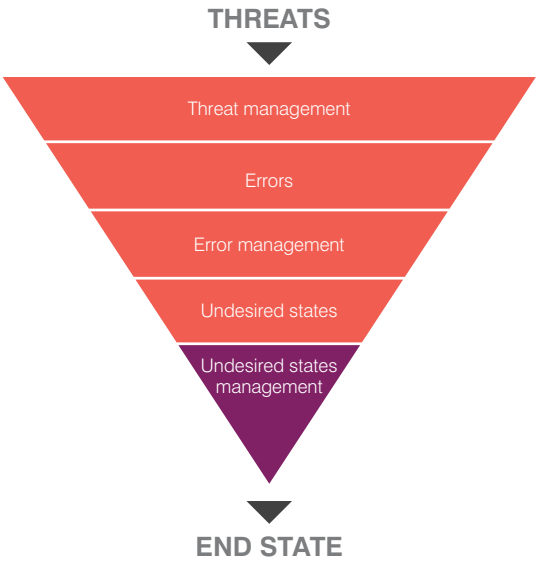

Figure 2 TEM triangle

While the basic concept of TEM is simple, including it into your standard practices is more challenging. But if you do, you will see the benefit of a planned and structured approach to staying ahead of the aircraft—and staying safe.

After the following gear-up accident in a Cessna 210 in the US, the pilot described the lead-up to the accident. Despite his training and the gear horn warning, he had failed to put the gear down before landing. Here's his analysis using the TEM model of the threat and error triangle pathway (see diagram above).

Threat management

- The pilot was coming home from a long flight and long day, feeling fatigued and struggling to keep on top of things.
- On arrival at his destination, ATC switched runways on him at the last minute. He became flustered as he had planned and briefed landing on runway 36, and now had to quickly switch to runway 27.
- There was a significant crosswind and he was concerned that his crosswind skills were not up to par. He hadn't practised crosswind landings for a long time.

Errors

- The pilot was interrupted during his descent checklist and did not complete it.
- He was surprised by the late runway change and did not complete his descent or before-landing checklists.
- He was having difficulty making the cross-wind correction for the pattern on the second runway.

Error management

- The pilot did not attempt to complete the descent checklist.
- He did not attempt to complete the before-landing checklist.
- He was barely managing the errors he was making correcting for the crosswind.

Undesired states

- The aircraft engine was running hot because the descent checklist wasn't completed.
- The gear wasn't down because the before-landing checklist wasn't completed.
- The flaps were not configured for landing.
- The aircraft wasn't lined up with the runway.
- Undesired state management nil.

End state

- Because of this event sequence, the aircraft landed on its belly, necessitating a new engine and new propeller. Extensive mechanical work was needed to fix the belly. Luckily there were no injuries to the pilot or his passengers.

So, how do you prevent errors from multiplying and putting you in an undesired aircraft state? In this case, a go-around would have provided time to get everything together and sort things out.

Consider how you could have anticipated and briefed yourself for the threats and errors on this day and the countermeasures that you could have put in place to manage the situation and avoid an undesired aircraft state you couldn't control.

Consequences of poor TEM

The following example describes a series of events which led to the death of a patient.[5] While it is from the health sector, it illustrates how unmanaged threats and errors can lead to disaster.

A patient died in 2001 in a well-run oncology unit in the UK. Chemotherapy for his leukaemia comprised two drugs: cytosine (to be administered through the spine) and vincristine (to be given intravenously).

The senior registrar was supervising the senior house officer, who was passed the cytosine, then the vincristine, and wrongly administered both to the patient through the spine.

This lethal error occurred despite product warnings, a body of literature that stressed the dangers, previous well-publicised cases, local protocols, and elaborate pharmacy defences which should have ensured that the drugs were never administered at the same time (or on the same day).

Numerous background threats and errors conspired:

- The senior doctors assumed that the juniors knew their subject (it was later argued that the relevant induction and training systems had been faulty). *Threat*.
- In the senior house officer's previous workplace, two syringes containing different drugs were commonly given simultaneously into the spine. *Threat*.
- The patient had arrived late for his therapy and extra efforts had been made to accommodate him before the day-ward closed. *Threat*.
- The staff member who went to collect the drugs from the pharmacy did not know they should be separated, so they were transported together. *Error*.
- The nurse delivering them to the bedside also brought them together. *Error*.
- The senior registrar did not notice that the vincristine was to be given intravenously. *Error*. Or that it was prescribed for the following day. *Error*.
- The labelling and the general appearance of the two syringes were similar. *Threat*.
- The senior registrar said at one stage he wrongly thought the second drug was methotrexate, which is given through the spine, partly because vincristine should not be available on the same day. *Error*.
- The senior house officer was surprised to be given a second syringe, so queried the drug and the route verbally, although not strongly enough to avoid the disaster that followed. *Failed opportunity to trap*.
- Connectors for both the syringes—to either the lumbar puncture needle or to the intravenous cannula—were interchangeable. *Threat*.

As newcomers to the hospital, the junior doctors assumed that:

- the organisation had all its procedures in place
- the other doctor was competent to do what he was doing
- the other doctor had read the patient's record.

Both doctors overrode an all-important final clue: *they were presented with something that was not routine and that they did not understand*. A more experienced and more safety-aware doctor might have taken this non-routine event as a sign to stop, take stock, reflect and reassess the situation.

The error, therefore, was caused by a long chain of latent conditions which created a threat, and active failures that could have been 'trapped'. In this case, mitigation was not possible and the patient died.

Assessing the application of TEM

Let's conclude by considering how a charter operator could develop a simple program to assess the practical application of TEM.

Such a program should answer the following questions about an operator's pilots.

- Do they recognise, assess and manage potential threats?
- Do they diligently follow standard operating procedures and show evidence of situational awareness to avoid and trap errors?
- Do they apply strategies to manage and mitigate the effects of any errors?
- Do they manage any undesired aircraft state and return to normal operations successfully?

Assessors need evidence that threat and error management is being practised; they can't assume that competent TEM was used just because a flight was completed safely.

Since observation is the only way to gather this evidence, it is important to actively question the pilot pre-flight, in-flight and post-flight to understand why specific TEM techniques were applied. However, the assessor should not distract the pilot.

On an assessment flight it is unlikely a competent pilot will get into an undesired aircraft state or, if it occurs, fail to correct it. It may therefore be necessary to set up a theoretical situation. For example:

- create a scenario that will be analysed during the pre-flight briefing
- when approaching a destination airport, simulate a thunderstorm over the airfield
- simulate a radio failure approaching a reporting point or entering a control zone
- simulate a precautionary or forced landing
- simulate an instrument or display failure.

The following list of competencies may be useful as a starting point for an assessment program:

Maintains effective lookout

- Maintains lookout and traffic separation using a systematic scan technique determined by traffic density, visibility and terrain.
- Maintains radio listening watch and interprets transmissions to determine traffic location and intentions of traffic.
- Performs airspace-cleared procedure before commencing any manoeuvres.

Maintains situational awareness

- Monitors all aircraft systems using a systematic scan technique.
- Collects information to facilitate ongoing system management.
- Monitors flight environment for deviations from planned operations.
- Collects flight environment information to update planned operations.

Assesses situations and make decisions

- Identifies problems.
- Analyses problems.
- Identifies solutions.

Assesses solutions and risks

- Decides on a course of action.
- Communicates plans of action (if appropriate).
- Allocates tasks for action (if appropriate).
- Takes actions to achieve optimum outcomes for the operation.
- Monitors progress against plan.
- Re-evaluates plan to achieve optimum outcomes.

Sets priorities and manages tasks

- Organises workload and priorities to ensure completion of all tasks relevant to the safety of the flight.
- Puts the safe and effective operation of the aircraft ahead of competing priorities and demands.
- Plans events and tasks to occur sequentially.
- Anticipates critical events and tasks to ensure completion.

- Uses technology to reduce workload and improve cognitive and manipulative activities.
- Avoids fixation on single actions, tasks or functions.

Maintains effective communications and interpersonal relationships

- Establishes and maintains effective and efficient communications and interpersonal relationships with all stakeholders to ensure the safe outcome of the flight.
- Defines and explains objectives to applicable or involved parties.
- Demonstrates a level of assertiveness that ensures the safe completion of the flight.
- Encourages passengers to participate in and contribute to the safe outcome of the flight.

Recognises and manages threats

- Identifies relevant environmental or operational threats that are likely to affect the safety of the flight.
- Develops and implements countermeasures to manage threats.
- Monitors and assesses flight progress to ensure a safe outcome.
- Modifies actions when a safe outcome is not assured.

Recognises and manages errors

- Applies checklists and standard operating procedures to prevent aircraft handling, procedural or communication errors and identifies committed errors before safety is affected or aircraft enters an undesired state.
- Monitors aircraft systems, flight environment and crewmembers, collects and analyses information to identify potential or actual errors.
- Implements countermeasures to prevent errors, or acts in the time available to correct errors before the aircraft enters an undesired state.

Recognises and manages UAS

- Recognises UAS.
- Prioritises tasks to ensure management of UAS.
- Manipulates aircraft controls or systems or modifies actions or procedures to maintain control of the aircraft and return to normal flight operations, in the time available.

Key points for professional pilots

The threat and error management (TEM) approach recognises that making errors is a normal part of human behaviour that can and should be managed. It promotes a philosophy of anticipation or 'thinking ahead'.

The three basic components of the TEM model are threats, errors and undesired aircraft states (UAS). It is important that crews know when to switch from error management to undesired aircraft state management.

Pilots who develop strategies or countermeasures such as planning, and review or modification of plans, tend to have fewer mismanaged threats, commit fewer errors, and have fewer undesired aircraft states.

Key points for charter operators

Charter operators can develop simple programs to develop and assess the practical application of TEM by their flight crews and to provide assurance that their flight training, checking and standard operating procedures are working effectively to manage safety.

TEM programs are designed to question and observe pilots before, during and after flights to determine whether pilots recognise, assess and manage potential threats; diligently follow standard operating procedures; demonstrate situational awareness to avoid and trap errors; apply strategies to mitigate the effects of any errors; and manage any undesired aircraft state to successfully return to normal operations.

Operators should seek evidence that TEM is being routinely practised rather than assuming it is. They should focus on making TEM training and observations a positive shared learning and continuous improvement experience for their people and their organisation.

Resources

FURTHER READING

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KEY TERMS

error Flight crew actions or inactions that lead to a deviation from crew or organisational intentions or expectations, reduce safety margins or increase the probability of adverse operational events on the ground and during flight.

human factors (HF) Optimising the relationship within systems between people, activities and equipment.

non-technical skills (NTS) Specific human factors competencies, such as look out, situational awareness, decision making, task management and communication.

threat Events which occur beyond the influence of the flight crew, increase operational complexity and which must be managed to maintain the margin of safety.

threat and error management (TEM) The process of detecting and responding to threats and errors to ensure that the ensuing outcome is inconsequential, i.e. the outcome is not an error, further error or undesired state.

undesired aircraft state (UAS) Pilot induced aircraft position or speed deviations, misapplication of flight controls, or incorrect systems configuration, associated with a reduced margin of safety.

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