1.1 Introduction to Human Performance

CAE's Vision

To be the worldwide partner of choice in Civil Aviation, Defense and Security, and Healthcare by revolutionizing our customers' training and critical operations with digitally immersive solutions to elevate safety, efficiency, and readiness.

CAE aims to provide training for the whole pilot life cycle. Whilst we already have many areas that cover the technical training, this human performance guide sets out the non-technical skills training that develops and integrates Crew Resource Management (CRM) training from Knowledge Skills and Attitude (KSA) at Airline Transport Pilot's License (ATPL) and Flight Training Organization (FTO) level, up to command and instructor levels within business, commercial, and helicopter aviation.

In the past, non-technical skills have often been referred to as 'soft skills', in comparison to 'hard skills' which are those required to do a task or job. However, this has created a misconception where 'hard' technical skills are seen in opposition or mutually exclusive to 'soft' non-technical skills. As a result of this misconception, soft skills are often seen as less important. To counteract this false impression, the preferred term has evolved to 'Human Skills'[i].

Human Skills: Human skills (sometimes called 'soft skills') are the non-technical skills that aren't traditionally taught as part of an education curriculum but that enable us to function at our optimum.[ii]

Structure of the Human Performance Guide

This human performance guide provides advice and guidance for clients and instructors in any CAE program. It is divided into 3 sections:

Section 1. *Introduction chapters:* basic concepts in behavioral psychology, learning sciences and aviation frameworks

1.1 Introduction
1.2 Basics of Human Behavior
1.3 Competency Based training and Assessment (CBTA)
1.4 Threat and Error Management (TEM)

Section 2. *Pilot competencies*: one chapter per ICAO competency, with hints and tips for empowering pilot skills in reference to the ICAO observable behaviors.

2.1 Application of Procedures and Knowledge
2.2 Communication
2.3 Flight Path Management- Automation
2.4 Flight Path Management- Manual
2.5 Leadership and Teamwork
2.6 Problem solving and Decision Making
2.7 Situational Awareness
2.8 Workload Management

Section 3. *Application chapters:* covering more in-depth concepts, with practical tips for functional use of the knowledge and skills.

3.1 Surprise, Startle, and resilience
3.2 Culture
3.3 Psychological Safety
3.4 Sensory Illusions
3.5 Leadership Command and Mentoring
3.6 Briefing and Debriefing

Crew Resource Management

Crew Resource Management (CRM) is a flexible, systematic method for optimizing human performance in general, and increasing safety, by:

1. recognizing the inherent human factors that cause errors and the reluctance to report them,
2. recognizing that in complex, high-risk endeavors, teams rather than individuals are the most effective fundamental operating units, and
3. effectively mobilizing all available resources to reduce the adverse impacts of those human factors.

Aircraft accidents have played a key role in highlighting the need for a new tool to deal with the human errors that were cited as major causes:

- 1977 brought about one of the worst loss of life accidents when two Boeing 747s collided on a runway in Tenerife. That accident occurred in part because of a communications breakdown in the cockpit.
- In 1978, United Airline 173 crashed into the Portland suburbs when the aircraft ran out of fuel. The crew had been distracted with a minor landing gear problem.

In 1979, the National Aeronautics and Space Administration (NASA) created a workshop entitled "Resource Management on the Flight Deck". This workshop was the culmination of research conducted by NASA in the early 1970s which identified the human error aspects of aviation accidents. After the NASA workshop, in 1981, United Airlines initiated the first CRM program. Conducted in a seminar-type setting, the United Airlines program and other first-generation programs used psychology as a foundation and were based on management training principles. Many of the courses were well received.

By the 1990s, CRM was a global standard in aviation, leading to more research in the field, which is still ongoing and developing today. Most of this research is founded in the 1994 University of Texas Human Factors Research Project (partnered with Delta Airlines) where they developed the Line Operations Safety Audit (LOSA). In 1999, LOSA was endorsed by ICAO and then built upon with many elements including Threat and Error Management (TEM).

Since its first introduction, CRM has developed through 6 generations.

1st Gen	Programs were focused on business management, and strategies were typically generalized and abstract.
2nd Gen	After 1985, CRM transitioned from "Cockpit" to "Crew" Resource Management. Topics expanded to distinct modules on decision-making, team building, and breaking error chains.
3rd Gen	Programs evolved to a much broader spectrum, integrating CRM into technical training. The flight crew concept was extended to other employee groups, including flight attendants and maintenance personnel.
4th Gen	Advanced Qualification Program (AQP) begins, allowing airlines to customize their training. Line Oriented Flight Training (LOFT) became an integral part.
5th Gen	Introduction of error management, recognizing that human error is inevitable and must be actively managed.
6th Gen	Further development into threat management, resulting in CRM skills being applied not only to avoid, trap, or mitigate errors, but also to identify threats within the work environment. The combination became known as Threat and Error Management (TEM).

Rather than having the goal of eliminating error entirely, CRM provides tools to recognize errors, threats, and deficiencies, with a view to mitigating their effects to the best degree possible. This table was developed to provide a clear representation of CRM.

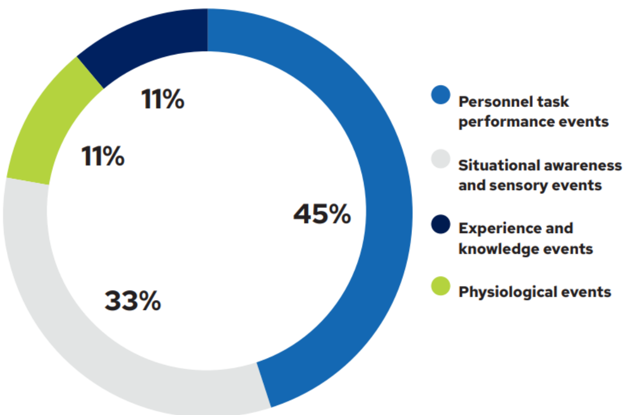
CRM is:	**CRM is not:**
▪ a comprehensive system for improving crew performance ▪ designed to address the entire crew population ▪ a system that can be extended to all forms of flight crew training ▪ an opportunity for individuals to examine their behavior and make decisions on how to improve cockpit teamwork ▪ designed to use the crew as the unit of training	▪ a 'quick fix' that can be implemented overnight ▪ a training program administered to only a few specialized or 'fix-it' cases ▪ a system where crews are given specific prescription on how to work with others on the flight deck ▪ another form of individually centered crew training ▪ a passive lecture style classroom course ▪ an attempt by management to dictate cockpit behavior

Human Factors

Human Factors is about people in their living and working situations; about their relationship with machines, with procedures and with the environment about them, and about their relationships with other people.[iii]

The EASA Annual Safety Review 2020 still showed a concerning number of human factors and human performance related accidents.

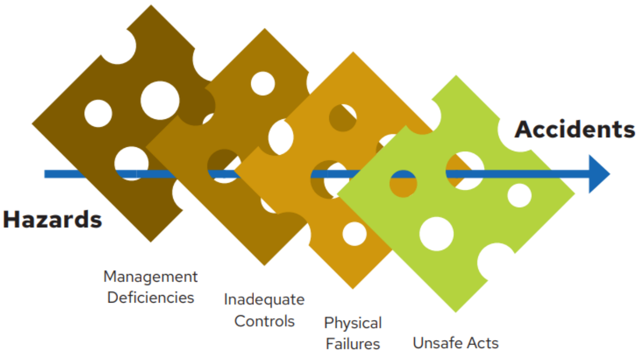
"Approximately a quarter of commercial air transport large aeroplane accident and serious incident reports identify human factors (HF) or human performance (HP) issues.".[iv]



This shows us that while aviation safety has increased in terms of the technological and mechanical aspects of flight, the human skills need to be improved.

Dr. James Reason developed the Reason, or "Swiss Cheese" Model in the late 1990s[v], to explain how systems components are like slices of cheese, each playing a role in the defense of the system. An accident will occur if we do not have sufficient mitigation for each of the four basic layers within this model.

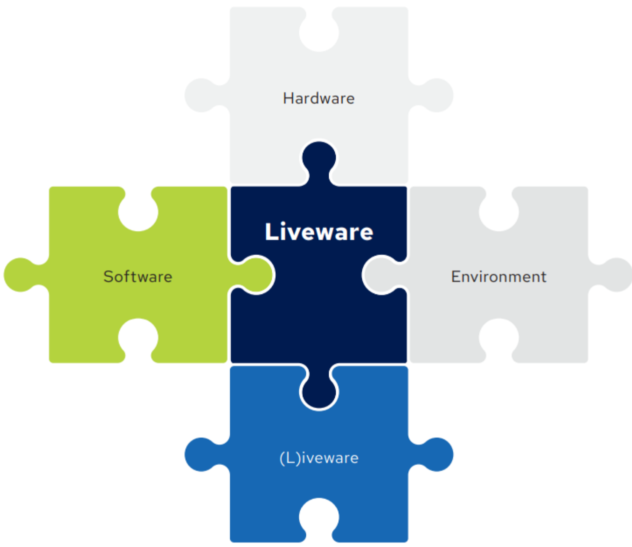
- Management deficiencies
- Inadequate controls
- Physical failures
- Unsafe acts



The holes in the layers of interventions represent imperfections that, if lined up with holes in subsequent layers, will, one-by-one, allow an error to pass through the system. Ultimately, if there are enough holes aligned, then an error will travel through and cause an undesired state where safety margins are degraded. This is where accidents and/or incidents occur.

SHELL Model

Early in a pilot's career, understanding the interactions of human factors with CRM issues can be daunting. The SHELL model[vi] provides an easy way to classify interactions so we can better understand how to manage them.



The SHELL Model was developed by Elwyn Edwards in the early 1970s[vii] and subsequently adapted into a building block structure by Frank Hawkins in 1984[viii]. SHELL is derived from the names of the various building blocks which relate to the various components of a system.

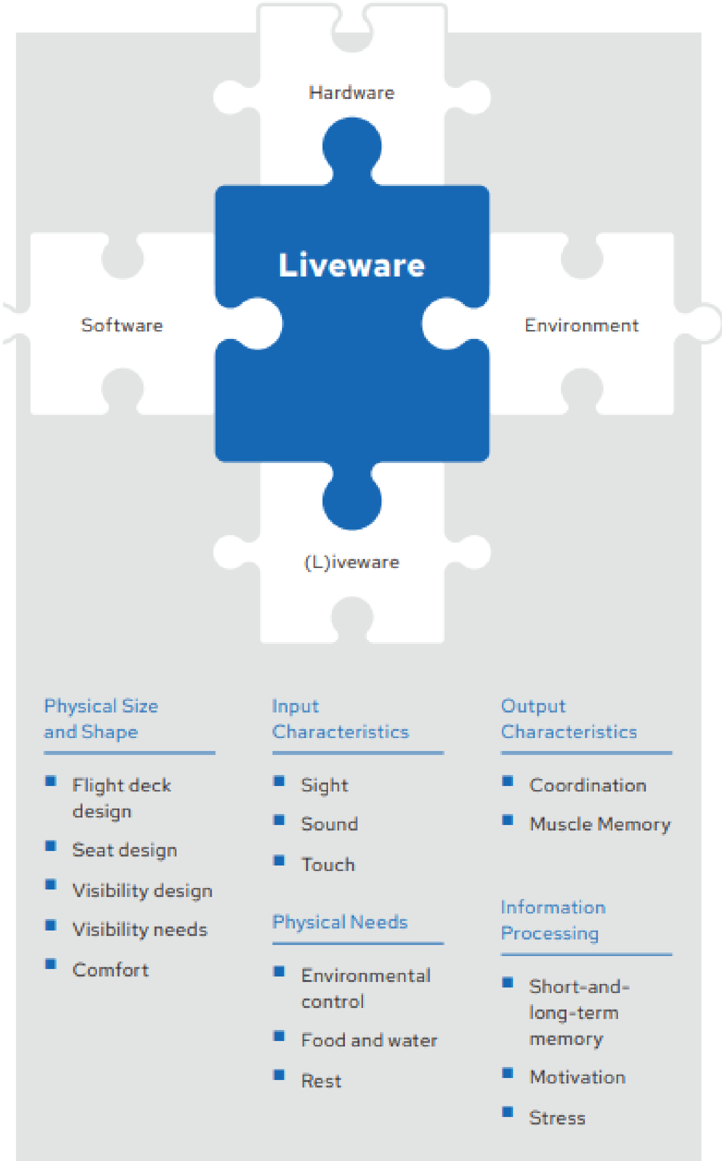
Each element must be lined up to fit into the central Liveware. If not, their mismatch describes a source of human / machine interface error.

Central Liveware

In the center of the model, liveware represents the human operator component. It is considered the most flexible, and most critical point of the system. Yet it is also the most fallible and resistant to change or improvement. Central Liveware is constrained by several characteristics, each is associated with relevant scientific fields of study.

Humans collect and respond to information from the world around them through their senses. The efficiency and quality of this sensory perception can be affected by various physical, mental and/or biological factors. In turn this will affect the decisions based on the perceptions.

Human physical characteristics must be considered when designing equipment including body measurements and movements. The data for determining these design factors comes from the study of anthropometry, biomechanics, and ergonomics.



Elwyn Edwards (1972) and Frank Hawkins (1984)

Ergonomics is a science-based discipline that brings together knowledge from other subjects such as anatomy and physiology, psychology, engineering, and statistics to ensure that designs complement the strengths and abilities of people and minimize the effects of their limitations.

Liveware - Software Interface

The liveware-software (L-S) interface includes humans and the non-physical aspects of the system, such as procedures, manual and checklist layout, symbology, and computer programs. If the software is not designed well, the output may be negatively affected. However, this can be masked by a human's ability to compensate. L-S problems often contribute to accidents but are difficult to observe and consequently more difficult to resolve.

Liveware – Environment Interface

The liveware-environment (L-E) interface was one of the earliest recognized in flying. Environmental tolerances, along with confined spaces and a boring or stressful working environment are known to affect performance and well-being. Initially, the measures taken all aimed at adapting the human to the environment, by designing such devices as helmets, flying suits, oxygen masks, and G-suits. More recently this has been reversed by adapting the environment to match human requirements, for example pressurization, air-conditioning systems, and soundproofing.

Illusions and disorientation have been cited in many aviation accidents. Perceptual errors induced by environmental conditions such as illusions during approach and landing continue to challenge flight crews.

Today, new challenges have arisen, such as ozone concentrations, radiation hazards, disturbed biological rhythms and related sleep disturbance and deprivation.

Liveware – Liveware Interface

The liveware-liveware (L-L) interface is that between the central Liveware component and the people who interact with it. This can be internally between the crew, as well as external to the aircraft, the engineers, ground crew, air traffic controllers etc.…

Many incident and accident causes have been traced to the breakdown of teamwork, and therefore, Crew Resource Management becomes key to safety. This interface is managed through skills of leadership, crew co-operation, teamwork, and personality interactions. Corporate culture, corporate climate and company operating pressures can also significantly affect human performance.

Liveware – Hardware Interface

The interface between central liveware and hardware (L-H) is also known as the human-machine interface. It includes such things as seat design, display designs, and information processing systems. Modern transport aircraft have used human-machine interface studies to improve the interaction between the pilots and the aircraft. Automation is the most common source of disconnects between the human and the system, and there is an entire chapter dedicated to automation in this guide.

Summary

- Crew Resource Management was developed to focus on human skills alongside technical skills, to improve aviation safety
- Human factors are still causing aviation incidents and accidents.
- The Swiss Cheese model can help visualize how layers of protection are needed to prevent threats or errors slipping through to cause an accident.
- Interactions that must be considered within Human Factors can be simplified with the SHEL(L) model.

Further Reading

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[iv] EASA Annual Aviation Safety Review. 2020. Available at : https://www.easa.europa.eu/sites/default/files/dfu/easa_asr_2020.pdf
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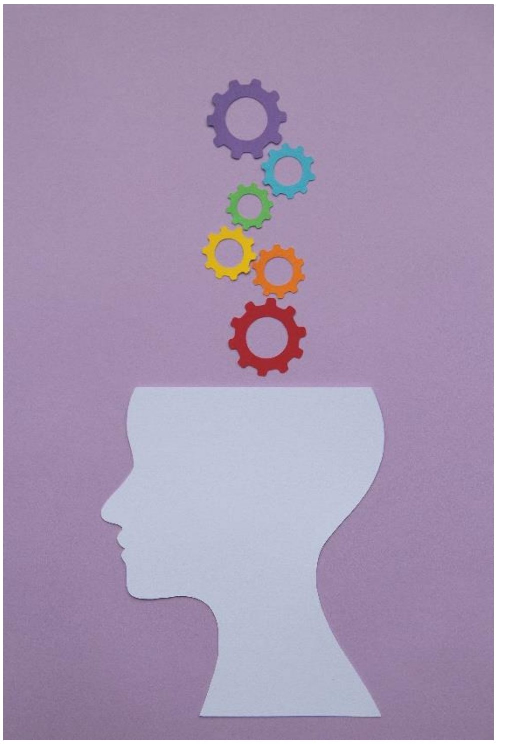
1.2 Basics of Human Behavior

Human behavior is at the center of our everyday experience; it shapes our lives and the lives of those around us. Behavior and its consequences influence what we learn, who we become, and what we will do. This is the essence and intent of teaching and learning.

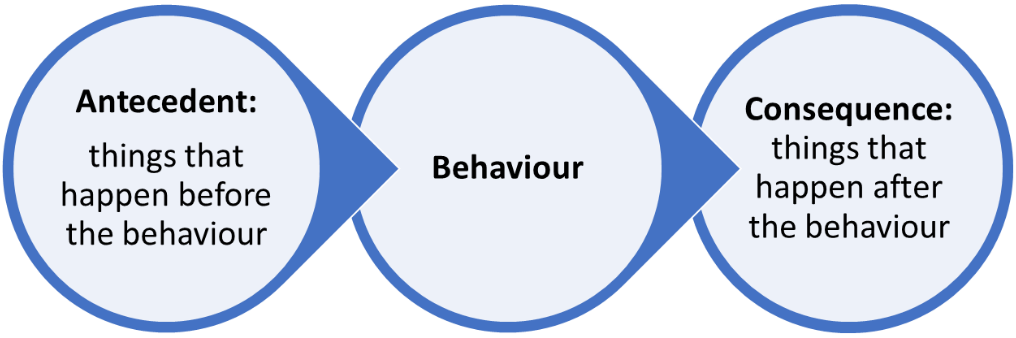


Everyone has a vested interest in understanding behavior. Parents, partners, teachers, trainers, co-workers – we all attempt to demystify and influence the behavior of others. Our inherent interest in behavior is a good thing because it motivates us to discover the 'whys' of behavior. However, it can also be unfortunate because the multitude of available 'common sense' explanations for behavior are strong competition for less imaginative, scientifically valid explanations. Although the science of human behavior is complex, there are some basic principles that can help us to better understand not only why we do what we do, but what we can do to improve our knowledge and skills.

Basic principles

Behavior is everything a person does, including overt behavior like moving and speaking as well as covert behavior like thinking, feeling, and decision-making.

Behavior is everything a person does, including overt behavior, like moving and speaking, as well as covert behavior like thinking, feeling, and decision-making. However, behavioral scientists view behavior not in isolation, but as a whole unit comprising behavior and context. Examining behavior involves understanding not just the action itself, but the important aspects of the context in which that action occurs. These aspects can be boiled down to the things that happen before behavior – the situation, or events and conditions that were present when an action occurred, and the results that happen after the behavior – the consequences, or events produced by that same action.



Here are two simple examples of behavior in context:

Scenario 1

Situation	There is a red warning light indicating the kitchen stove is hot.
Behavior	I touch the stove.
Consequence	My finger is burned, and it is painful.
Future Behavior	Next time I see that red warning light, I won't touch the stove, so I don't get burned again.

Scenario 2

Situation	I'm at a bakery and I'm hungry.
Behavior	I purchase a slice of pink cake.
Consequence	I find the pink cake to be delicious and am no longer hungry.
Future Behavior	Next time I am hungry and nearby the bakery, I may very well purchase the pink cake again.

We are all (willing or unwilling, intentional, or unintentional) behavioral engineers, and we benefit from understanding that the only way to sustainably influence anyone's behavior, including our own, is by shaping the context in which it occurs. One way to influence behavior is to change the situation. Some examples of situations or things that happen before behavior include the physical environment, any form of training, job aid, checklist, cue or reminder. These things all occur before we behave and, in many cases, occur before we enter the operational environment. Let us see how this looks in practice.

Suppose we aim to ensure first officers are comfortable pointing out a risky situation to the captain, so we provide training on the appropriate competency and observable behavior:

Scenario 3

Situation	The first officer (FO) and captain have received training on the relevant pilot competency and associated observable behavior; during today's flight the FO recognizes a risk worth reporting to the captain.
Behavior	The FO advises the captain of a risk.
Consequence	The Captain thanks the FO for their observation and the risk is mitigated.
Future Behavior	The FO will be happy to report all observed risks to the captain.

In the above scenario, the situation itself has an influence on behavior. Without prior training, the first officer and the captain may not have independently developed the competencies required to allow this behavior. Often, using interventions like training can cue the desired behavior, and no other interventions are necessary. However, there are limitations to influencing only the situation present before behavior. If these cues fail to match the real-world consequences we encounter, they will not be influential for long. Here is an example of how that might happen:

Scenario 4

Situation	The first officer and captain have had training on the pilot competency framework and associated observable behaviors, but the captain has simply played along during training and has not taken to heart the feedback received during training. During today's flight the FO recognizes a risk worth reporting to the captain.
Behavior	The FO advises the captain of the risk.
Consequence	The captain tells the FO to mind their own business and stop worrying.
Future Behavior	The FO may choose not to report risks to the captain.

Note how the situations and behaviors of the first officer in scenarios 3 and 4 are almost exactly the same. Viewed in isolation, the first officer's behavior itself does not say much about why it is occurring. In this case, any behavioral evidence of prior training may be completely absent in future behavior. In other words, despite having attended the same training, this FO may never challenge this captain again because of the consequences experienced in the 'real world'.

It is the relationships that form between actions and contexts that explain and predict future behavior. In scenarios 3 and 4, it is the consequence applied by the captain that leads to the change in future behavior on the part of the first officer. It is important to understand the power of consequences; this is how sustainable learning happens. If consequences shape our future behavior, how can we use this idea to improve training and learning?

Defining Behavior

If we aim to influence behavior, we must first create a shared understanding of the desired or undesired behavior, and for that reason, behavior should be defined in a way that is as objective as possible. This helps to reduce the amount of interpretation required by others, ensuring most people observing the behavior would agree that it either has or has not happened. Here are some examples of the way we could define behavior:

Example 1

Statement 1: The captain has a great attitude.

Statement 2: The captain demonstrated exemplary Leadership and Teamwork.

Statement 3: The captain led and worked as a team member in an exemplary manner, by always demonstrating the following OBs, which enhanced safety .

- Encourages team participation and open communications
- Considers inputs from others
- Gives and receives feedback constructively

An example of this performance is when he responded to the first officer's concern by saying, "I really appreciate you bringing that to my attention. I agree that the safest course of action would be to wait until that weather clears".

Example 2

Statement 1: The cadet is a poor team member.

Statement 2: The cadet has trouble expressing thoughts and ideas in a team setting.

Statement 3: When the cadet made a suggestion during today's group exercise, he spoke so quietly that the other team members may not have heard, and they did not respond to his suggestion. Then the cadet backed away from the table and folded his arms. He did not make any more suggestions for the remainder of the exercise.

Most of us are accustomed to discussing behavior at the level of detail found in statement 1 of both examples. However, each of us will have a slightly different image in our minds after reading statement 1, and the image that comes to mind is a result of our unique personalities and histories. This is perfectly fine if we are not attempting to influence behavior, but which statement is most clear? Which statement would be the most helpful way to phrase feedback meant to shape behavior? In many cases, the level of detail found in statement 2 may be sufficient, but when providing or receiving feedback to an individual or in a training report, statement 3 is the best way to go. This level of detail minimizes the risk of miscommunication.

Kind and Wicked Learning Environments

Although 'common sense' may suggest that experience is enough to acquire knowledge and skills, the consequences that occur naturally after behavior are not always guaranteed to teach the 'right' lessons.

Sometimes, natural consequences are perfectly matched to encourage desired behavior. Psychologist Robin Hogarth[ii] refers to these situations as *kind learning environments*. In a kind learning environment, consequences link outcomes directly to the appropriate actions or judgements and tend to be both accurate and abundant. It is often the case that technical skills are acquired in a kind learning environment, like learning to swing a golf club or learning to land an aircraft. In these cases, consequences are quick, obvious, and always accurate. Any time your landing technique is correct, the outcome should be better than if it was incorrect. Our skills improve with repetition, reliably over time in these environments, as long as we are attentive to outcomes. These kinds of learning environments allow us to develop accurate, intuitive judgements about our own behavior.

Kind learning environments are situations in which consequences link outcomes directly to the appropriate actions or judgements and tend to be both accurate and abundant.

However, not all learning environments are kind, and some are downright wicked. In a *wicked learning environment*, consequences in the form of outcomes of actions are poor, misleading, or altogether missing. Imagine a novice pilot, during simulator training, delaying the decision to land at the nearest suitable airport due to a fire warning, with no safety consequences. Without suitable feedback (for example uncontrollable smoke, or significant system failures), she might never appreciate the potential outcome of her poor decisions and wouldn't know how to react correctly, the next time; lessons learned in wicked environments are likely to be mistaken.

Wicked learning environments are situations in which consequences in the form of outcomes of actions are poor, misleading, or altogether missing.

Nontechnical skills, especially interpersonal skills, are often acquired in a wicked learning environment. The above scenario 4 is a good example of mismatched consequences. In this case, the first officer was behaving as he had been trained, but the captain inadvertently provided a consequence that does not encourage safe behavior. Scenario 3, on the other hand, is an example of a consequence that is likely to encourage safe behavior, despite occurring in the same unreliable, wicked learning environment. When there are mismatched, conflicting consequences for the same behavior (as in scenarios 3 and 4), it becomes difficult to acquire new skills. In these situations, it is important to ensure consequences, typically in the form of verbal feedback, are designed to encourage the acquisition of knowledge and skills.

Summary

- Behavior is everything a person does, including overt behavior like moving and speaking as well as covert behavior like thinking, feeling, and decision-making.
- The only way to sustainably influence anyone's behavior, including our own, is by shaping the context in which it occurs. This can be done by changing the things that happen before behavior (situation) or changing the things that happen after behavior (consequences). However, consequences are what maintain behavior change.
- Kind learning environments are situations in which consequences link outcomes directly to the appropriate actions or judgements and tend to be both accurate and abundant.
- Wicked learning environments are situations in which consequences in the form of outcomes of actions are poor, misleading, or altogether missing.
- To encourage learning, focus on creating kind learning environments where possible and arranging for the provision of helpful consequences in wicked learning environments.

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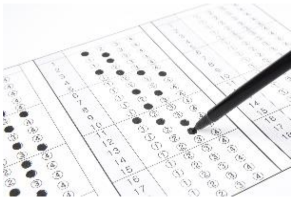
[ii] Hogarth, R. M., Lejarraga, T., & Soyer, E. (2015). The Two Settings of Kind and Wicked Learning Environments. *Current Directions in Psychological Science, 24*(5), 379–385.

1.3 Competency Based Training and Assessment

Competence

All individuals in the pilot community come from diverse backgrounds in terms of culture, education, life experience and more. So, it is unreasonable to assume that two pilots with the same number of flight hours will be matched in piloting ability. A pilot's ability can be judged depending on how many hours they have flown, how many approaches they have performed, and how recently they were last airborne. This system can show varying degrees of 'experience levels' and may account for skill erosion. However, there are many reasons (individual ability, personal life, distractions, or time spent on the ground) hours flown may not necessarily equate to how good a pilot is at their job. In fact, previous assumptions were that accident rates decrease with increased total flight hours (TFH), however, FAA research[i] has shown this is not the case.

	***Training:*** structured delivery of knowledge and skills with learning as its desired outcome. Teaching, imparting knowledge and skills, and modifying behavior
	***Assessment:*** the systematic process of gathering and documenting evidence of knowledge, skills, and attitudes. Gathering evidence via written or oral exams, investigations, simulations, and observations
	***Evaluation:*** the attribution of value to the performance to the assessment made. Determining whether the minimum criteria, grade, or level has been met.

There was a need for more effective and efficient training to:

- accommodate varying levels of student knowledge, skills, and attitudes (KSA);
- allow for different acquisition/ learning rates throughout a course;
- maintain a minimum pass standard;

To achieve this goal, aviation looked to the education sector for a solution, and found Competency Based Training and Assessment, (CBTA).

Competency Based Training and Assessment: Training and assessment that are characterized by a performance orientation, emphasis on standards of performance and their measurement and the development of training to the specified performance standards[ii].

The defining feature of CBTA is the focus on individual *competence*. In a CBTA framework, progression is only achieved through mastery of knowledge and skills as opposed to the accrual of hours. Students must continue to study and practice each element until they meet the required level of competence.

Competence: Ability to demonstrate the necessary skills, knowledge and behaviors that are required to perform a task to a prescribed standard.

There are several differences between traditional hours based and CBTA frameworks:

Traditional Hours-Based	CBTA
▪ Students advance based on final or overall course *grades*. ▪ If mastery is not achieved, the student receives a *low grade* but continues. ▪ Students may fail to meet the *minimum grade* and repeat a section. ▪ If a student does not meet the minimum standard in a set time, there is *little flexibility*.	▪ Students advance based on *mastery*. ▪ Each student may progress at a *different pace*. ▪ A student will have *multiple opportunities* to demonstrate mastery. ▪ Learning time is *flexible* to allow student growth and attainment of *superior performance*.

While CBTA allows for a personalized training experience for students, it does require flexibility from the organization, training design teams and instructors. The reward for implementing a competency framework lies in the ability to clearly define high standards and guarantee students meet these in all areas before graduation.

Competency

Within CBTA, the words competency (a collection of knowledge, skills, and attitudes) and competence (a level of mastery) are often confused. To explain this distinction, let us look further into the meaning of competency.

Competencies are often used to create a list of demonstrable characteristics and skills that are required to participate fully in a particular role. These lists are often referred to as '*competency frameworks.*'

Technical and Non-Technical competencies, are defined as:

Competency: A dimension of human performance that is used to reliably predict successful performance on the job. A competency is manifested and observed through behaviors that mobilize the relevant knowledge, skills, and attitudes to carry out activities or tasks under specified conditions. [iii]

Development of CBTA Regulation

Aviation safety has incrementally progressed, over time, by focusing on specific areas of activity. From its origins until the end of the 1960s, safety performance was primarily enhanced through technical developments which reduced the rate of aircraft system failures or malfunctions. Lessons learned from accident and incident investigations were integrated into the ICAO Standards and Recommended Practices (SARPs).

SARPs are adopted by the Council under the provisions of the Convention.

Standard: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as **necessary** for the safety or regularity of international air navigation and to which Contracting States **will conform** in accordance with the Convention; in the event of impossibility of compliance, notification to the Council is compulsory under Article 38.[iv]

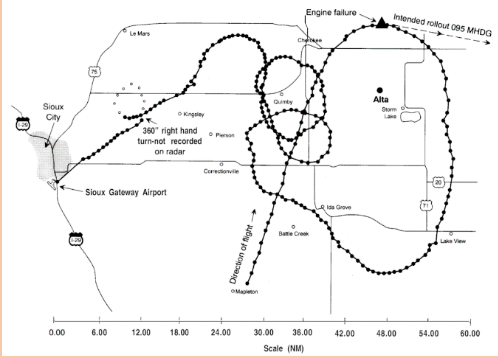
Recommended Practice: Any specification for physical characteristics, configuration, matériel, performance, personnel or procedure, the uniform application of which is recognized as **desirable in the interest of safety,** regularity, or efficiency of international air navigation, and to which Contracting States **will endeavor to conform** in accordance with the Convention.[v]

In simple terms:

- Standards are mandatory
- Recommend Practices are encouraged but not mandatory

By the early 1970s, the frequency of aviation accidents had significantly declined due to major technological advances and enhancements in safety regulations. However, the 1980s saw significant growth in passenger air traffic which required innovation in technology and operations to sustain the expansion of air travel. Nevertheless, safer operations had an unexpected side effect; crews were no longer accustomed to increasingly rare technical failures.

United Airlines Flight 232, Sioux City, 19 July 1989.[vi]



- DC10 suffered catastrophic failure in the tail mounted engine.
- Shrapnel from the engine cut lines of all three hydraulic systems leaving the aircraft with no control via the flight controls.
- The cockpit voice recording showed the crew demonstrated excellent non-technical skills in discussions which enabled them to problem solve and control the aircraft by use of asymmetric thrust of the two remaining wing-mounted engines.
- Despite exceptional handling, the engine response rate was not sufficient to stop the last-minute roll encountered during the high-speed landing. The DC10 lost its right wing, rolled over and caught fire.
- Sadly 112 died, but 184 survived due to the skills of the crew.

The Sioux City accident is an excellent example of the importance of non-technical skills. The crew had never encountered an emergency of this nature, nor heard of any previous accidents like this. Amongst several findings, the NTSB praised the crew for their CRM[vii], which they had been trained for in the early CRM programs after Tenerife and Portland.

1989: NTSB quoted United 232 as evidence of the success of CRM training and the FAA made CRM training mandatory. At the same time, ICAO published Digest Number 2 (now CAP 720), discussing the benefits of Cockpit Resource Management and Line Orientated Flight Training (LOFT).

Despite the emergence of CRM, training and assessment were still in a traditional method. Crews would complete a specified number of hours of training and would be assessed within a well-defined technical framework such as the FAA Practical Test Standards (now superseded by the Airman Certification Standards). Training was only focused on technical competencies, but data continued to illustrate that a large number of accidents had root causes linked to poor non-technical skills (NTS).

2002: The aviation training community came to realize the need to evolve training away from a tick-box approach, and to focus more on creating resilient pilots. The Flight Crew Licensing and Training Panel (FCLTP) identified a clear need for a new licensing and training document, called the Procedures for Air Navigation Services -Training (PANS-TRG). Whilst it was too detailed to take the form of 'standards,' it was of sufficient importance to provide universal benefit to member States.

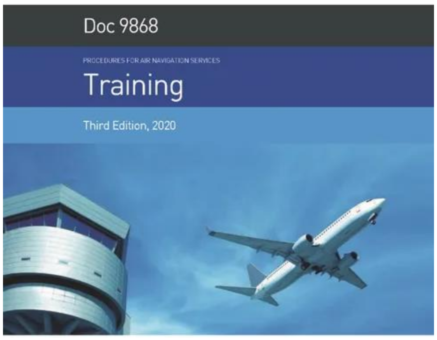
2006: ICAO supported a performance-based approach to training with the publication of standards for the multicrew pilot license (MPL). This was the first ICAO licensed

Competency-based Training and Assessment (CBTA) framework and was adopted in Europe as a common standard by the Joint Aviation Regulations (JARs).

2007: The IATA Training and Qualification Initiative (ITQI) set up a working group comprised of representatives from airlines, civil aviation authorities, academic institutions, aircraft original equipment manufacturers, international organizations, pilot representative bodies and training organizations. Their goal was to establish a new method for the development and conduct of recurrent training and assessment, today known as *Evidence-Based Training (EBT)*.

2013: CBTA principles were extended to operator recurrent training with the publication of ICAO, Doc 9995, Manual for Evidence-based Training (EBT), where it has been accepted as an alternative means of compliance for recurrent training and checking by several Civil Aviation Authorities.

2014: The Australian Civil Aviation Safety Authority (CASA) introduced competency-based training standards for all CASA flight crew qualifications.

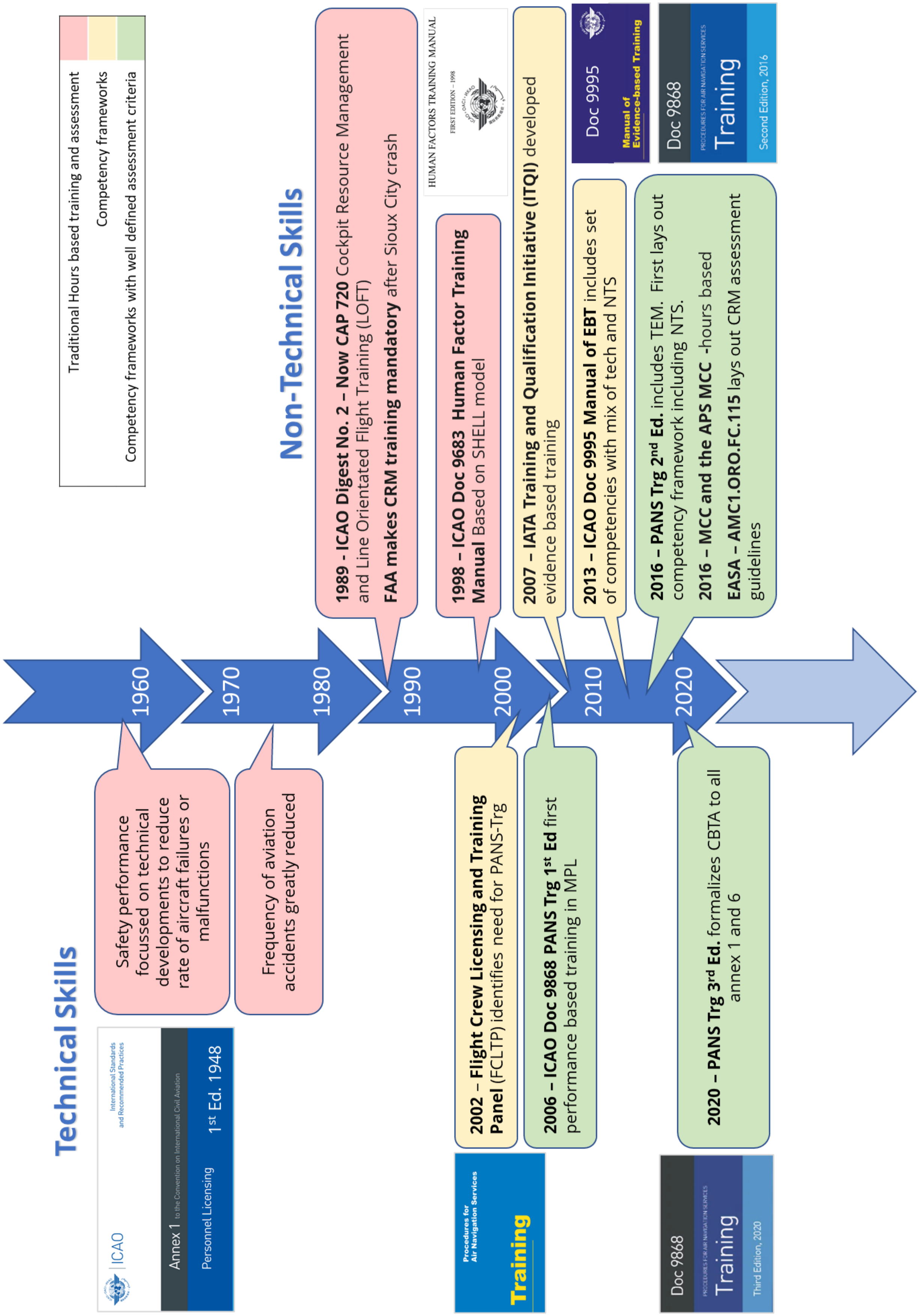


2016: ICAO published the second edition (Amendment 5) to PANS-TRG, General provisions for competency-based training and assessment. This defined the role of the pilot competencies in the context of Threat and Error Management (TEM) and provided a basis for further development of CBTA.

2018: ICAO endorsed the IATA definitions of a pilot instructor-evaluator competency set.

2020: ICAO published the third edition (amendment 7) to PANS-TRG, which formalized the global expansion and applicability of CBTA principles to all licensing training (ICAO Annex 1) and operator training (ICAO Annex 6).

The timeline of regulation development can be split into technical and non-technical skills and demonstrates the move from traditional training to competency-based training and assessment. This graphic shows, in red, where traditional hours-based training and assessment were used, and in yellow, where the competency frameworks are being developed. Finally, green shows when the frameworks include a detailed list of assessment criteria, performance indicators or observable behaviors.


Traditional Hours based training and assessment
Competency frameworks
Competency frameworks with well defined assessment criteria
Technical Skills
ICAO
International Standards and Recommended Practices
Annex 1 to the Convention on International Civil Aviation
Personnel Licensing
1st Ed. 1948
Safety performance focussed on technical developments to reduce rate of aircraft failures or malfunctions
Frequency of aviation accidents greatly reduced
1960
1970
1980
1990
2000
2010
2020
Non-Technical Skills
1989 - ICAO Digest No. 2 – Now CAP 720 Cockpit Resource Management and Line Orientated Flight Training (LOFT)
FAA makes CRM training mandatory after Sioux City crash
1998 – ICAO Doc 9683 Human Factor Training Manual Based on SHELL model
HUMAN FACTORS TRAINING MANUAL
FIRST EDITION – 1998
Procedures for Air Navigation Services
Training
2002 – Flight Crew Licensing and Training Panel (FCLTP) identifies need for PANS-Trg
2006 – ICAO Doc 9868 PANS Trg 1st Ed first performance based training in MPL
2007 – IATA Training and Qualification Initiative (ITQI) developed evidence based training
2013 – ICAO Doc 9995 Manual of EBT includes set of competencies with mix of tech and NTS
Doc 9995
Manual of Evidence-based Training
2016 – PANS Trg 2nd Ed. includes TEM. First lays out competency framework including NTS.
2016 – MCC and the APS MCC -hours based
EASA – AMC1.ORO.FC.115 lays out CRM assessment guidelines
Doc 9868
PROCEDURES FOR AIR NAVIGATION SERVICES
Training
Second Edition, 2016
2020 – PANS Trg 3rd Ed. formalizes CBTA to all annex 1 and 6
Doc 9868
PROCEDURES FOR AIR NAVIGATION SERVICES
Training
Third Edition, 2020

IATA and ICAO Competency Frameworks

The IATA Training and Qualifications Initiative (ITQI) was implemented in 2007 to modernize maintenance training, align regulations to provide a more flexible aviation workforce, and to attract younger generations to the aviation industry. In conjunction with ICAO and the International Federation of Air Line Pilots' Associations (IFALPA), the following 8 Core Competencies were agreed upon:[viii]

Application of Procedures Identifies and applies procedures in accordance with published operating instructions and applicable regulations, using the appropriate knowledge.	**Communication** Demonstrates effective oral, non-verbal, and written communications, in normal and non-normal situations.
Leadership & Teamwork Demonstrates effective leadership and team working.	**Problem Solving & Decision Making** Accurately identifies risks and resolves problems. Uses the appropriate decision-making processes.
Situation Awareness Perceives and comprehends all the relevant information available and anticipates what could happen that may affect the operation.	**Workload Management** Manages available resources efficiently to prioritize and perform tasks in a timely manner, under all circumstances.
Flight Path Management: Automation Controls the aircraft flight path through automation, including appropriate use of flight management system(s) and guidance	**Flight Path Management: Manual** Controls the aircraft flight path through manual flight, including appropriate use of flight management system(s) and flight guidance systems.

Despite 'Knowledge' being mentioned in the ICAO descriptor of Application of Procedures, it was felt this competency needed highlighting further. In the most recent edition of ICAO Doc 9868, PANS – Training, there was the addition of the underpinning competency, 'Application of Knowledge', bringing the total of PCs to nine[ix].

Application of Knowledge

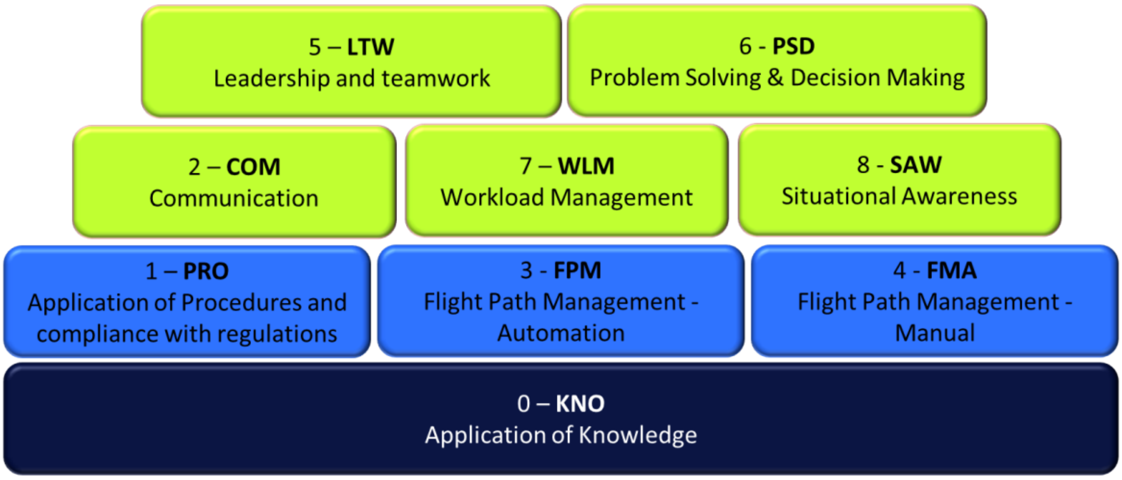
Underpinning the pilot competencies is the 'application of knowledge' which collectively refers to the ability of the pilot to:

- recall and proactively update relevant knowledge; and
- apply acquired knowledge to the operational environment, including TEM.

CAE's Pilot Competencies

The PCs were numbered and given short abbreviations. These are CAE's 9 Pilot Competencies:

0. Application of Knowledge (KNO)
1. Application of Procedures & Compliance with Regulations (PRO)
2. Communication (COM)
3. Aircraft Flight Path Management - Manual Control (FPM)
4. Aircraft Flight Path Management – Automation (FPA)
5. Leadership and Teamwork (LTW)
6. Problem Solving and Decision Making (PSD)
7. Workload Management (WLM)
8. Situational Awareness and Management of information (SAW)



So how do we define 'Application of Procedures,' compared to 'Application of Knowledge.' Is it possible to have one without the other? Can they be taught separately?

Definitions from the field of learning science can give some answers.

Knowledge: Facts, information, and skills gained through education or experience. The theoretical or practical understanding of a subject.

Procedure: A sequence of actions that is the established or official way of doing something.

By using these definitions, it becomes evident that knowledge is a forerunner to a procedure. In some frameworks, KNO and PRO are combined to Application of Procedures and Knowledge (APK). Throughout this hp guide, we will continue to concentrate on the CAE 9 Pilot Competencies.

Observable Behaviors

Each competency listed in a framework needs further definition so they can be taught and assessed. To achieve this, lists of behaviors which may indicate the presence of each competency were created, to assist both students and instructors to understand what is meant by the competencies; these are called observable behaviors.

Observable Behavior (OB): A single role-related behavior that can be observed and may or may not be measurable.[x]

Observable behaviors can cause a lot of discussion, but very simply, there are either seen (observed), or not. A full list of OBs can be found in ICAO Doc 9868 PANS Training, and in each chapter of section 2 of this human performance guide.

It is often easier to think of this in terms of technical skills; for example, did the pilot fly the approach within limits? The answer is simply yes or no for this single event. In technical terms we can imagine a case where the student flies a single approach and was within most of the limits. They may also fly several approaches, but only fly it 'acceptably' less than half the time. There would therefore be a lower grade given as this student lacks the reliability in this skill.

This table describes the similarities between technical and non-technical observed behaviors.

	Technical Skill – Approach path	**Non-technical skill - Communication**
How many	Does the student fly a single maneuver within most of the deviation limits?	Does the student demonstrate many aspects of communication as required?
How often	Can the student reliably repeat this exercise to the same standard?	Does the student reliably demonstrate these behaviors throughout the learning event?
How well	Did this result in a safe or unsafe outcome?	

Importantly here, we note that non-technical skills cannot be assessed in a single task – they have to be considered over a period of time for that learning activity.

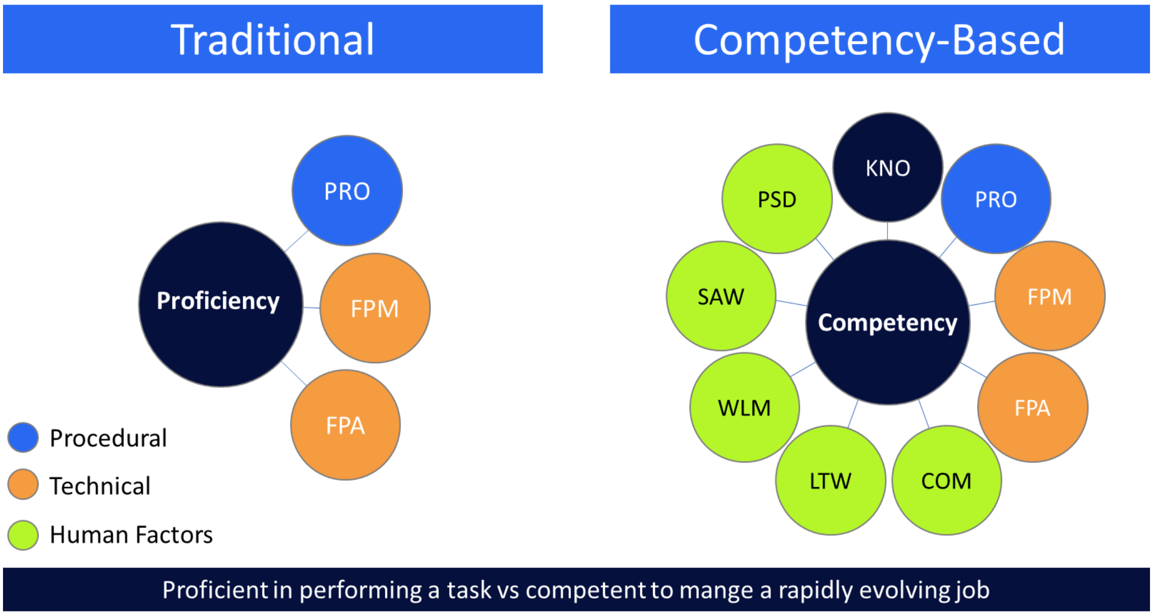
Traditional training versus CBTA

Each of the CAE pilot competencies and associated OBs are discussed further in their own chapter, but a good point to address now is a common question from instructors:

"How does CBTA change what I already do?"

The answer to this question lies in two halves:

- ***Technical Skills:*** Good instructors have always coached and mentored their students through difficult elements, ensuring competence is achieved before moving on. For the technical skills, CBTA simply gives more guidance material on how these elements can be taught and assessed.
- ***Non-technical Skills***: CBTA now treats non-technical skills with the same regard as technical skills. CBTA includes a shift towards ensuring non-technical skills courses are not simply attendance courses, but that mastery of each competence area is achieved. This creates a need for new methods of training and assessment, so an instructor knows how to teach them and how to judge when students meet required standards.



Irrespective of whether we are training and assessing technical or non-technical skills, in CBTA, the assessment of competence performed by an instructor or evaluator, during and at the end of a course of training, is equally focused on both, the process and the outcome.

Other Regulatory CBTA Frameworks

EASA Knowledge, Skills, and Attitudes

EASA uses the 9 competencies, referenced by the numbers previously described[xi]. Then at FTO level, and in a purely theoretical knowledge instruction environment, the competencies are again adapted slightly. Here, FPA and FPM are irrelevant (until the flying phase) and therefore are replaced with Threat and Error Management (including resilience and UPRT), and Mental Mathematics.

FAA Training and Assessment

Training and assessment of non-technical Skills are reflected in the FAA slightly differently to those found in ICAO and EASA documentation. Human skills concepts are addressed in the CRM Advisory Circulars[xii], in the following categories:

a. Communications Processes and Decision Behavior.
   (1) Briefings
   (2) Inquiry/Advocacy/Assertion
   (3) Crew Self-Critique (Decisions and Actions)
   (4) Conflict Resolution
   (5) Communications and Decision making
b. Team Building and Maintenance
   (1) Leadership/Followership/Concern for Task
   (2) Interpersonal Relationships/Group Climate
   (3) Workload Management and Situation Awareness
   (4) Individual Factors/Stress Reduction

While this list has obvious overlap to the EASA competency framework, there is no mandate to follow a competency-based approach. If a training organization wishes, they may follow the Advanced Qualification Program (AQP). [xiii]

> *"It (AQP) replaces programmed hours with proficiency-based training and evaluation derived from a detailed job task analysis that includes Crew Resource Management (CRM)."*

Within AQP, there is less guidance for assessment than seen in the EASA AMC[xiv]. It is the ATO's responsibility to align their training with the Aircrew Certification Standards (ACS). Therefore, there are no shared competencies, behavioral indicators, or criteria that are common throughout the FAA.

Instructor and Evaluator Competencies

Further to the pilot competencies, IATA set out the following Instructor and Evaluator Competencies (IECs)[xv]:

1. **Pilot Competencies:** The 9 Pilot competencies
2. **Management of the learning environment:** Ensures that the instruction, assessment, and evaluation are conducted in a suitable and safe environment.
3. **Instruction:** Conducts training to develop the trainee's competencies.
4. **Interaction with the trainees:** Supports the trainees' learning and development and demonstrates exemplary behavior (role model)
5. **Assessment and Evaluation:** Assesses the competencies of the trainee and contributes to continuous training system improvement.

Future chapters to this guide will include each of the IECs.

Summary

- Traditional training is based on duration only and will have a grade based on a summative assessment. Whereas CBTA is based on acquisition of knowledge and skills and is paced by the student's mastery (competence) before progression.
- Competency frameworks identify the knowledge and skills required to do a job; they include technical and non-technical skills.
- There are several competency frameworks, most commonly used is the ICAO 9 Pilot Competency Model, numbered 0-8, where zero is the underpinning Application of Knowledge
- Advanced Qualification Program (AQP) in the FAA is closest in scope to the ICAO CBTA program.
- Further competencies are listed for instructors and evaluators; the 5 IECs.
- While good aviation instructors have used elements of CBTA for many years, it has only been a regulated method of training since the first edition of PANS Trg in 2006 for MPL.
- Competencies that include the non-technical skills were included in CBTA in the Manual of evidence-based training in 2013.
- In CBTA, the assessment of competence, is equally focused on both the process and the outcome.

Further Reading

- IATA CBTA Centre at: www.iata.org/en/training/training-certifications/cbta-center/cbta-exellence/
- ICAO Doc 7300: Convention on International Civil Aviation
- Joint ICAO, IATA and IFALPA publication: Evidence-based Training Implementation Guide
- Kearns, et al. *Competency-Based Education in Aviation: Exploring Alternate Training Pathways.* United Kingdom, Ashgate Publishing Limited, 2016.

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ii ICAO. Doc 9995 AN/497 'Manual of Evidence-based Training'. First edition. 2013.
iii IATA GM. Competency Assessment and Evaluation for Pilots, Instructors and Evaluators. 2021.
iv ICAO Annex 1- Personal Licensing
v ICAO Annex 1- Personal Licensing
vi National Transportation Safety Board. November 1, 1990. NTSB/AAR-90/06. Archived from the original on October 24, 2018. Retrieved March 15, 2011.
vii "How Swift Starting Action Teams Get off the Ground: What United Flight 232 and Airline Flight Crews Can Tell Us About Team Communication" (PDF). Management Communication Quarterly. Vol. 19, no. 2. November 2005. Archived from the original on July 5, 2007.
viii ICAO. Doc 9995 AN/497 'Manual of Evidence-based Training'. First edition. 2013.
ix ICAO. Doc 9868 Procedures for Air Navigation Services, Training. Third edition. 2020.
x ICAO. Doc 9868 Procedures for Air Navigation Services, Training. Third edition. 2020.
xi EASA Easy Access Rules. AMC1 ORO.FC.231(b) Evidence-based training
xii FAA Advisory Circulars: 120-51E: Crew Resource Management Training & 121-42/43 for Leadership Command and Mentoring
xiii FAA Advisory Circular 120-54A: Advanced Qualification Program
xiv EASA Easy Access Rules for Air Operations. AMC1 ORO.FC.231(b) Evidence-based training
xv IATA GM. Competency Assessment and Evaluation for Pilots, Instructors and Evaluators. 2021

1.4 Threat and Error Management

To conclude the section 1 of this human performance guide, this chapter will explain Threat and Error management as the foundation of CBTA in aviation. While born from the world of aviation, these chapters will develop the competency ideas across other safety critical areas, such as healthcare, maritime, air traffic control and more.

You may recall from the Introduction chapter, the evolution of CRM to TEM:

Let us first define some important key terms [i]:

	Threat: events or errors that occur beyond the influence of the flight crew, increase operational complexity, and must be managed to maintain the margins of safety. Threats may lead to errors, undesired aircraft states, incidents, or accidents
	Error: action or inaction by the flight crew, that leads to a deviation from intentions of expectations.
	Undesired Aircraft State: aircraft position or speed deviations, misapplication of flight controls, or incorrect systems configuration, associated with a reduction in margins of safety.

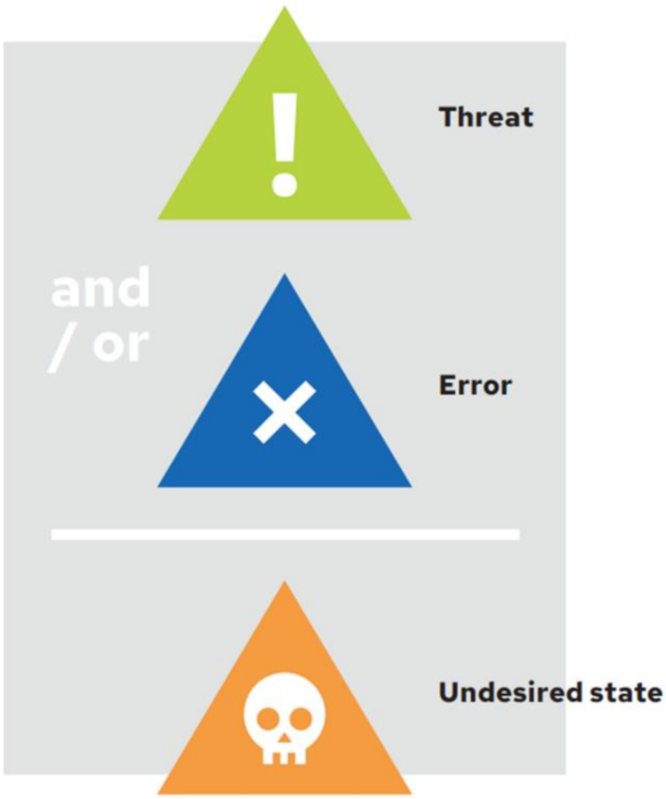
Forensic investigation and the use of hindsight provides valuable information after an accident or incident. Traditionally this was the only way to discover flaws in the system or in the humans operating it. But this was not sufficient, humans were still making mistakes and committing errors, some of which led to injuries and deaths.

	Accident: An unexpected and often unfortunate event that results in damage or injury.
	Incident: An event that can be considered a near miss, where there is the potential for damage or injury, or the outcomes were much less severe than they might have been.

To discuss the aspects of Threat and Error Management (TEM), this chapter will look at 'performance environments'. These are the location/scene/teams in which the work is being done, for example:

- A flight crew on a flight deck,
- A surgical team in an operating room,
- An engineering team in a maritime engine room.

The goal of TEM is to identify threats and errors quickly and accurately, then plan and implement appropriate responses to manage them. In simple terms, a threat and/or an error can lead to an undesired state where an accident or incident may occur.[ii]



Threats

Events or factors that are external to the performance environment are classified as threats. They are not necessarily deficiencies in the system, but events that increase the complexity of operations and therefore increase the likelihood of errors. Threats can be overt or latent.

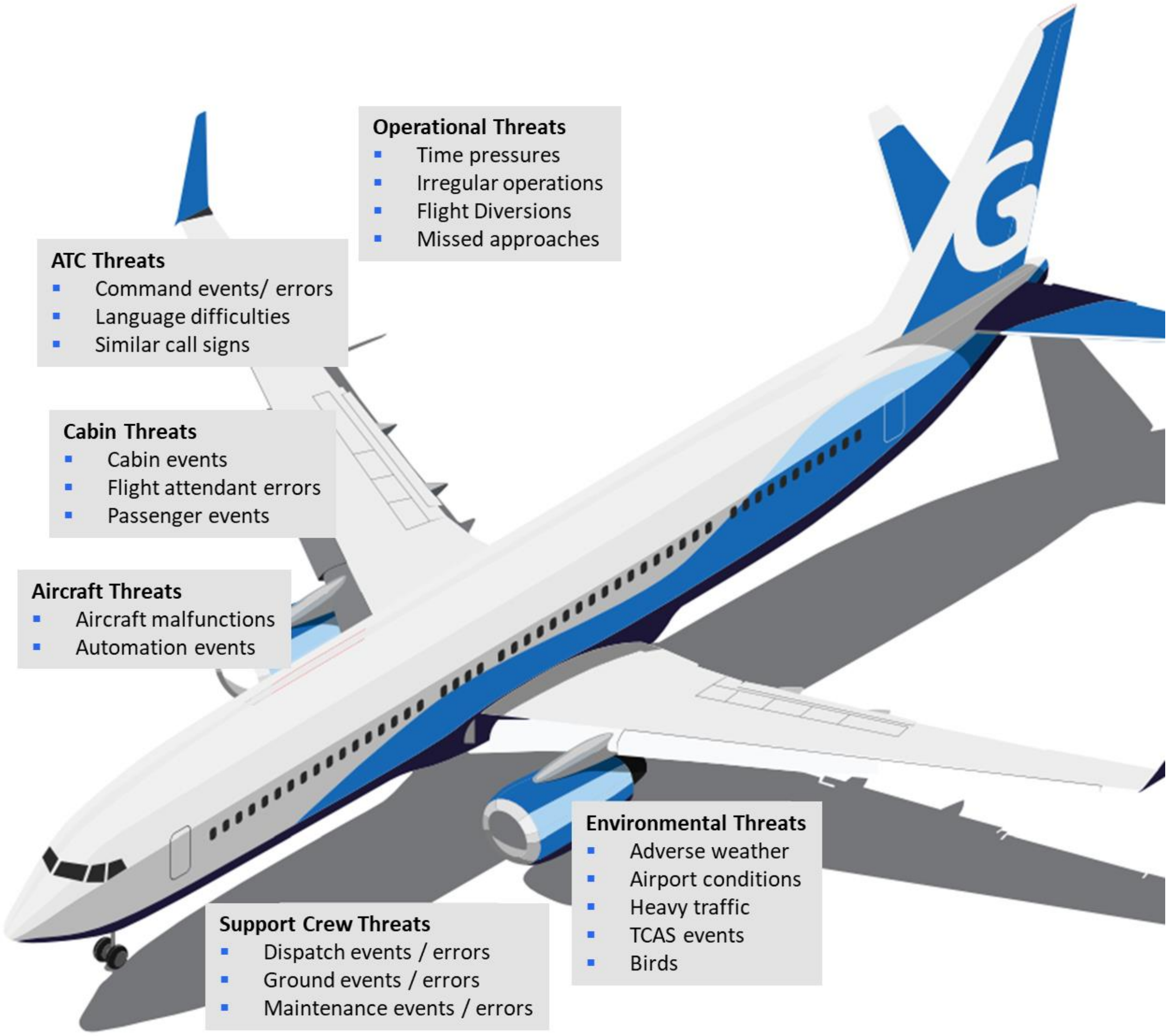
> ***Overt threats*** are well defined and observable. Little can be done to control them, so managing threats must become the focus for crews.

Examples include:
- poor weather (thunderstorms, adverse wind, turbulence) that could disrupt a flight schedule
- violent or abusive passengers, patients, people
- technology malfunctions, blank screens in a flight deck, on medical equipment of failed machinery

Overt threats are unavoidable in many performance environments, such as aviation, healthcare, and defense; so, managing threats must be a focus to increase safety.

> ***Latent threats*** are not readily observable and may conceal themselves within the operation itself.

Some examples of latent threats can be in relation to organizational culture or discrepancies within policies and procedures. These threats can be hard to see clearly; they may be masked by overt threats, or entirely unseen, until too late. Additionally, they are often complex and difficult to classify in terms that can easily show solutions. For example, there may be two conflicting policies/procedures that are rarely used together. But in those rare cases, it then emerges that both cannot be followed correctly, and give ambiguous results.


Operational Threats
Time pressures
Irregular operations
Flight Diversions
Missed approaches
ATC Threats
Command events/ errors
Language difficulties
Similar call signs
Cabin Threats
Cabin events
Flight attendant errors
Passenger events
Aircraft Threats
Aircraft malfunctions
Automation events
Environmental Threats
Adverse weather
Airport conditions
Heavy traffic
TCAS events
Birds
Support Crew Threats
Dispatch events / errors
Ground events / errors
Maintenance events / errors

Errors

There are four common types of error:

Slip: An incorrect action is performed, such as a substitution or insertion of an inappropriate action into a sequence that was otherwise good.

For example, a slip might be setting the wrong altitude into the mode selector panel, even when the pilot knew the correct altitude and intended to enter it.

Mistake: The human did what they intended, but the planned action was incorrect.

Mistakes can result from an incorrect diagnosis of a problem or a failure to understand the exact nature of the current situation. For example, it would be a mistake to shut down the wrong engine because of an incorrect diagnosis of a set of symptoms. The plan of action thus derived may contain inappropriate behaviors and may also fail to rectify the problem.

Lapse: Omission of one or more steps of a sequence.

A lapse could be missing one or more items in a checklist that has been interrupted by a radio call. Similarly, emergencies can often distract teams from their normal task, therefore creating lapses in those otherwise standard routines.

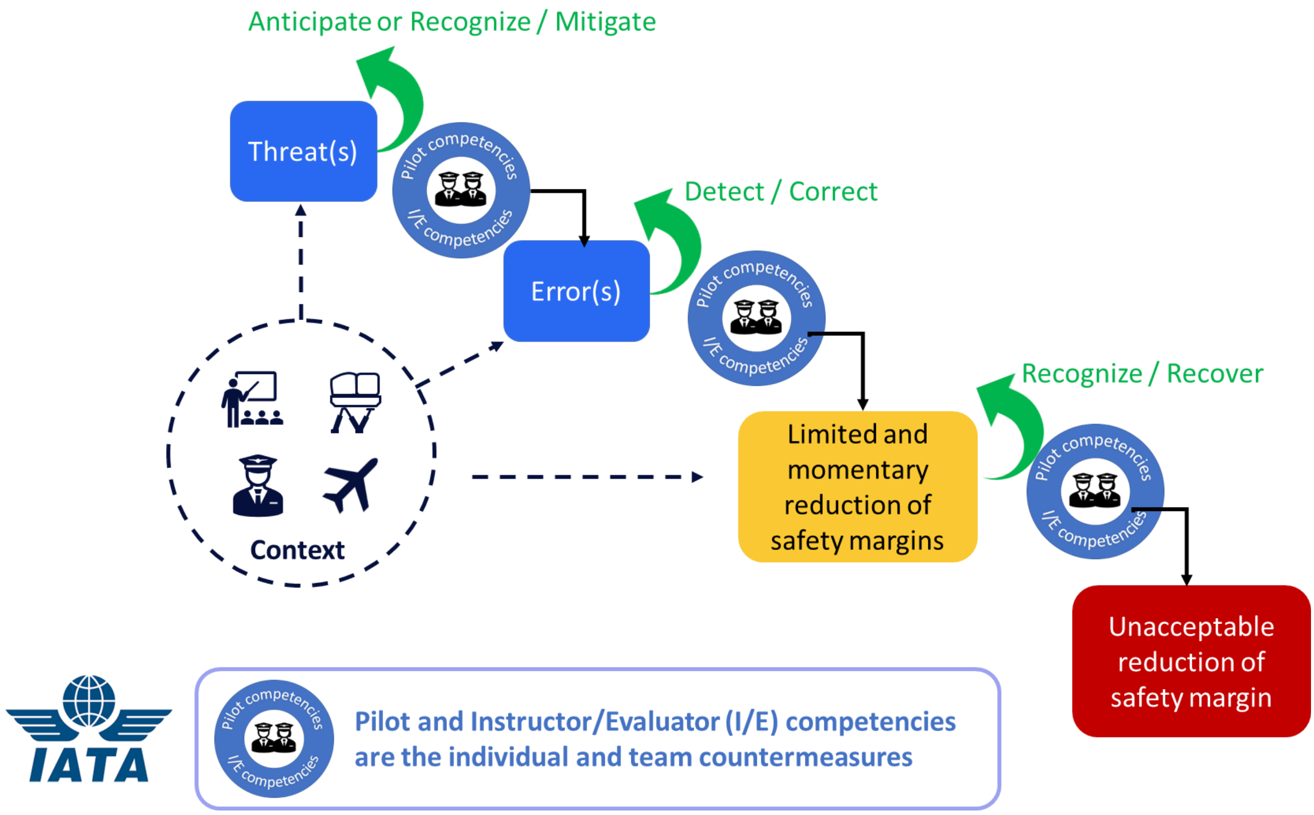
Violation: Failure to follow established procedures, or performance of actions that are generally forbidden.

Starting an approach in IMC when the broadcast weather was below your minima or continuing to attempt a landing without the required visual reference at the minima are examples of violations. Violations are generally deliberate. This does not mean they are malicious in intent, but that an action has been purposefully taken against the established procedure (although an argument can be made that some violation cases can be inadvertent). Violations are not restricted to regulation or other legal requirements, but can encompass a wide range of social, moral, and political issues too.

Threat and Error Management

Training has traditionally focused on eliminating error. This ignores the fact that errors are a by-product of human behavior. As Alexander Pope wrote, "To err is human"[iii]. Therefore, the outcome of managing errors can never be to eliminate them all. We must instead develop a range of countermeasures to give us some layers of defense against an undesirable outcome. IATA developed a diagram[iv] to demonstrate a few key points:

- TEM is applicable in various contexts – Not only in flight, but also in terms of the simulator, classroom activities as well as the organizational employees.
- Just like James Reason's Swiss cheese model, TEM countermeasures should be used, with the aim of preventing the escalation of a threat or error to any form of reduced safety margin, UAS, or accident/incident.
- The Pilot and Instructor Evaluator competencies (shown in the blue donut shapes) are the barriers we place to reduce the risk of a slide down the diagram.



Anticipate or Recognize/Mitigate

At the initial threat level, we aim to *Anticipate or Recognize/Mitigate* the threat. The outcome may lead to three possibilities:

1. A return to safe operations if the management techniques work
2. Trigger an error in the crew
3. Directly causes an Undesired Aircraft State (UAS) or an Incident/Accident

Undesired aircraft states are transitional states with a limited and momentary reduction in safety margins between a normal operational state and an unacceptable reduction is safety margin, such as in an incident/accident.

For example:
- Normal state: stabilized approach
- UAS: un-stabilized approach
- Incident/accident: runway excursion

Detect and Correct

If an error occurs (triggered or not by a threat), the crew will need to *Detect and Correct* the error in a safe and timely manner. This has three possible outcomes:

1. Return to safe operations
2. Initiate additional errors
3. Directly causes an Undesired Aircraft State (UAS) or an Incident/Accident

Recognize and Recover

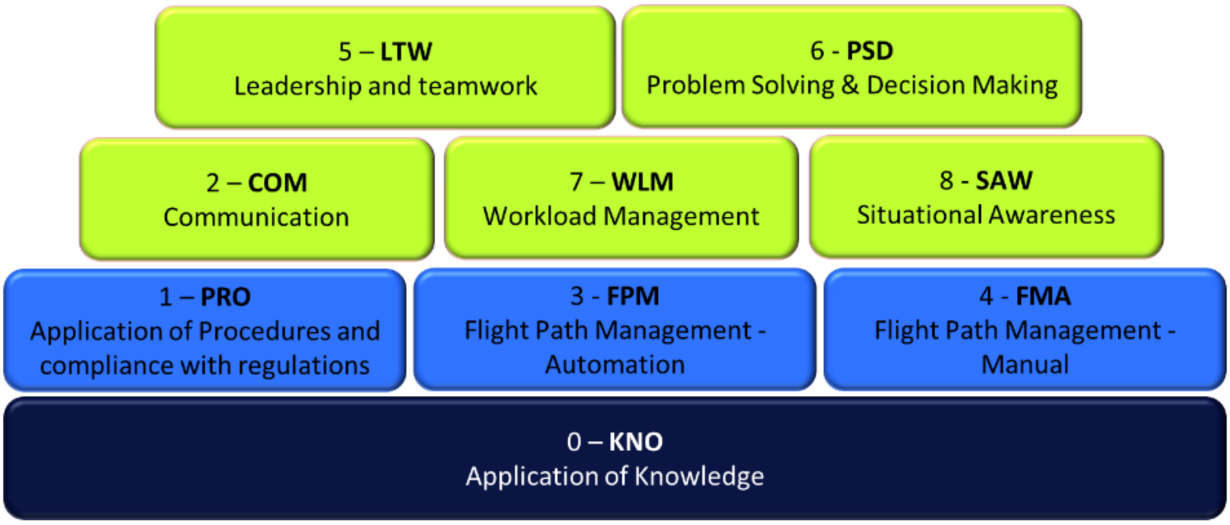
From the undesired state, the crew must prioritize actions to *Recognize and Recover* to safe flight. Again, there are three possibilities:

1. Recovery to safe operations
2. Initiate further error
3. An error induced accident or incident

The TEM Model shows that threats need to be managed as a first line of defense in limiting errors. It also shows that a threat can be as great a contributor as an error to an incident or accident.

TEM Countermeasures

The TEM countermeasures are the pilot competencies and instructor evaluator competencies introduced in the CBTA chapter. Here is an overview, and each will be discussed in much more detail in section 2 of this human performance guide.



If in doubt – always revert to:

Aviate - Navigate - Communicate

Operational Errors

Once some experience has been gained, it becomes useful to understand errors in a more operational sense, rather than the theoretical 'slip, lapse, mistake, and violation.' These are equally relevant across many performance environments, as shown by each example. Operational errors are put into 5 categories:

- Communication
- Procedural
- Proficiency
- Intentional non-compliance
- Operational decision

Communication error is a miscommunication, misinterpretation, or failure to communicate pertinent information.

In the 1990s, NASA launched the Martian Climate Orbiter[v] which included a Martian Polar Lander. Unfortunately, the orbiter and lander team had different measurement systems (metric and imperial) which were not communicated. The mix up caused the complete loss of both probes.

Procedural error is a deviation in the execution of a procedure where the intention was appropriate, but the execution was incorrect.

A procedural approach required an outbound heading from the beacon of 102M. However, the pilot inadvertently dialled 120M onto the course bar and flew the wrong outbound heading, ending up 19 degrees off course.

Proficiency error results from lack of knowledge or skills.

A surgical doctor had learned and practiced the steps required to perform a kidney transplant. However, once in the operating room, threats arose that forced a change of plan, but the doctor did not have the knowledge or skills to correctly complete the task.

Intentional non-compliance error is a willful deviation from regulations and/or procedures.

A busy port requires a local marine pilot to be onboard the tanker ship before entry into the narrow and congested waters. However, the captain was advised there would be a significant delay in getting a pilot out to them. The captain was under intense pressure to make up some lost time. Having visited the port many times before, the captain and crew felt comfortable with the procedure, and decided to enter the port under their own navigation and steering. The ship subsequently caught in an unexpected current and grounded on a sand bank.

Operational decision error is a decision-making error that is not standardized by regulations or procedures, unnecessarily comprising safety. This could be due to one (or more) of these 3 reasons:

1. the crew had more conservative options to choose from
2. the decision was not verbalized with the crew
3. the crew had time available but did not utilize it effectively to evaluate the decision

An aircraft is on a short haul turn around. The crew arrive late and are under intense time pressure. An issue that would normally necessitate further investigation was postponed due to the commercial time pressure perceived by the crew. The aircraft departed on time, but safety was compromised.

Summary

- To err is human
- Threats are beyond the influence of the crew and errors come from within.
- Threats can trigger an error, UAS and/or accident.
- The Pilot competencies and the Instructor Evaluator competencies are the TEM countermeasure to:
    - ***Anticipate or Recognize/Mitigate***
    - ***Detect/correct***
    - ***Recognize and recover***
- If ever in doubt, revert to - Fly, Navigate, Communicate. Fly the aircraft first!

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iv IATA White Paper. Competency-Based Training and Assessment (CBTA) Expansion within the Aviation System. 2021.

v https://solarsystem.nasa.gov/missions/mars-climate-orbiter/in-depth/