# UNDERSTANDING COMPLEX ASSESSMENT: A LESSON FROM AVIATION

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## Abstract

A variety of assessment methods are used in assessing performance in complex domains. These vary from paper-and-pencil tests to advanced simulation. The conventional approach to assessment of airline pilots' performance has focused on technical skills, such as flying an aircraft and related aeronautical knowledge including aerodynamics, aircraft systems, navigation, rules and regulations. While technical skills are important, over recent decades another set of pilot skills has been implicated in a majority of airline accidents. These skills, termed non-technical skills, include decision making, communication and teamwork. Although critical to airline safety, these non-technical skills are only now beginning to be transparently assessed. This paper presents empirical research that investigated current practice in how experienced senior pilots assess pilot performance. The research has led to a model for assessing pilots' performance (MAPP). Whilst this model has been developed for use in aviation, the paper discusses how the MAPP may have relevance to other professions and vocations for assisting in complex performance-based assessment.

Keywords: complex performance, performance-based assessment, performance assessment, pilots' performance, phenomenology, non-technical skills.

## 1 COMPLEX PERFORMANCE-BASED ASSESSMENT

Assessment plays an important role in developing individual and team performance [1]. With increasing complexity in the performance required by individuals or teams, making judgements about performance, too, entails corresponding complexity. This complexity is evident in such complex domains as flying an aircraft, working within a surgical team, supervising a building construction site or managing a school. Within some professions and vocations, poor performance can result in death, financial loss, or disproportionate risk to a community.

Assessment that determines whether or not the necessary standard of performance has been mastered, therefore, has a crucial role to play. The section that follows identifies some features of complex domains and approaches used to assess performance in these complex domains.

Complex domains are characterised by "significant ill-structured problems" [2], where the components are numerous and the relationships of the components can be unclear [3]. In addition, the problems presented in complex domains do not commonly have typical solutions. Nor is one possible solution always viewed as superior to another [2]. This complexity poses challenges to the validity - or appropriateness and adequacy - of performance-based assessment, with high validity implying that assessment measures what it claims to measure. The complexity also presents difficulties for reliability, or "consistency of assessment results" [4]. What, then, are the methods used in assessing performance within complex domains and how are the standards of performance identified?

The methods used in assessing complex performance are varied. Conventional paper-and-pencil tests are widely used, including in medicine [5], [6] and aviation [7]. However, in the quest to bring higher levels of realism into assessment, computers and simulation are seeing greater use. The methods used in medicine include standardised patients (person trained to simulate a patient), computer-based simulation, human patient simulation (replicated human body section or whole body simulator) and cutting edge virtual reality devices [8], [9], [10]. Many of these methods can be expensive, however, and they do not capture all the realities of performance. For example, they do not enable the assessment of skills such as decision making in real-time environments, and they tend to artificially compartmentalise skills [5]. It has been argued, for instance, that "problem solving, as an activity, is more complex than the sum of its component parts" [11]. Within aviation, simulation has been used over many years as a means of replicating the experience in real aircraft [12]. As technologies have

developed, these simulations have become increasingly high fidelity. The benefit of this approach is that pilots can be assessed on their performance while remaining safely on the ground, in a context where real-life assessment would expose pilots and those in the vicinity of an airport to considerable risk. For example, catastrophic engine failures low to the ground in large commercial jet aircraft are manoeuvres best assessed in the safety of a simulator.

Regardless of the methods used in assessing complex performance, a related issue is how the standard of performance is determined. For instance, a pass standard of, say, 80% may be decided on for a paper-and-pencil test. The degree of arbitrariness in this decision will impact upon its validity, although reliability may be considered high. In other cases, an expert may be required to use professional judgement to decide whether a particular performance can be regarded as achieving an acceptable standard. For example, observations may be undertaken by an experienced and qualified surgeon in assessing performance in surgery [5]. Where decisions such as these are not transparent, they can be subject to bias so that the assessor's pre-conceptions or prejudices can influence the decision reached [4].

One approach that is used in attempting to improve the transparency of assessing complex performance is the development of performance criteria. For instance, testing tools in the form of checklists are used in assessing procedural skills in surgery, as well as in assessing some of the broad surgical skills [5]. Specific performance criteria are also used to evaluate performance during promotion of business managers [13] or in reviewing how effectively school principals perform [14]. Judgement by assessors is still required, but it targets performance against specific criteria. Similar to simulations, there is a risk that skills can be compartmentalised in a way that does not adequately reflect performance in real-time situations. However, methods that introduce some form of transparency into the assessment of complex performance can contribute to overcoming the potential for bias. Each method for assessing complex performance is likely to have both advantages and limitations.

# 2 ASSESSMENT IN AVIATION

Against the background of the various forms of assessment that are outlined above, this section takes a closer look at the approaches to training and assessment of complex performance that historically have been adopted within aviation, including some limitations of these approaches. A recent empirical research study is then described that endeavoured to overcome some of the limitations of the earlier approaches to assessment of pilot performance. This study has produced a model for assessing the complex performance of flying an aircraft.

## 2.1 Historical view of training and assessment in aviation

Soon after World War Two, huge investments in aircraft design, systems and technology saw commercial aircraft becoming safer and more reliable, with a notable decrease in accidents. As aircraft technology and systems continued to improve, research during the 1980s began to demonstrate a shift in the percentage mix of accidents related to machine causes versus pilot error [15]. The research showed that the pilot was becoming far more frequently identified as the cause of aircraft accidents. Perhaps surprisingly, the research also pointed out that the main cause of pilot errors was not poor performance in technical skills, such as flying skills and associated technical knowledge [15]. Airline accidents were more commonly related to what became referred to as non-technical skills, such as communication, decision making and management. Accordingly, these non-technical skills have received heightened attention for over thirty years within aviation [15], [16].

As a result of the research findings, the airline industry began implementing new training approaches. Technical skills training, such as take-off and landing, and navigation, as well as training in technical knowledge, including aerodynamics, aircraft systems and rules of the air, have been based on an approach that has similarities to training apprentices for trades. As technical knowledge is directly related to flying an aircraft, practice has commonly occurred in an aircraft, although simulation is playing an increasing role. This approach has also been used in training pilots to fly large jet aircraft, with a similar focus on technical knowledge and flying skill [12]. Given the lack of evidence that training in technical skills was related to airline accidents, little change in these training approaches has occurred over the last thirty years [12]. However, recent research is now challenging some of the earlier research results [17].

Whilst technical skills training has remained largely unchanged, there has been some alteration in the approaches adopted in teaching non-technical skills. Following the identification of non-technical skills as the cause of pilot error, airlines tended to approach training as a classroom-based activity. Pilots were provided with information on broad topics relating to non-technical skills, such as teamwork, communication and decision making [16]. Although training on non-technical skills continues to be largely classroom-based, some airlines have extended this form of training into real-time training scenarios. For instance, in airlines where modern simulators are available, real-time training scenarios are used, which aim to integrate technical and non-technical skills. These scenarios typically occur under the instruction of a senior pilot, with a crew consisting of an aircraft captain and a first officer (or second-in-charge). The crew is required to deal with an emergency in real time, such as an engine failure in flight. In dealing with this kind of emergency, the crew would be required to secure the engine and identify available airports, and make final decisions on the best options available.

Similar to the training of technical and non-technical skills, the assessment of these skill areas has also been approached in disparate ways. The assessment of pilots' technical skills has a long history in line with their recognition as central to effective pilot performance. Assessment of technical skills occurs in two ways. Firstly, flying skills are assessed in either a simulator or real aircraft. The assessment is usually based on detailed and explicit criteria. For example, the acceptable standard for maintaining the cruising altitude of an aircraft is plus/minus 100ft. Secondly, aviation knowledge is tested using conventional paper-and-pencil tests. The typical approach is multiple-choice questions that are used to assess a variety of knowledge, including rules of the air, aerodynamics, and navigation theory and aircraft systems [7].

In contrast, the assessment of non-technical skills has been less transparent. (For a detailed treatment of assessment of non-technical skills, see [18].) During the late 1990s, the European aviation authorities were concerned with a lack of transparency in assessment of non-technical skills and set out to develop a set of objective assessment criteria. Prior to this, it had been argued that senior pilots assessed non-technical skills using their own intuitive judgements [7]. The new criteria developed to assess non-technical skills were known as NOTECHS. They consisted of four categories: cooperation; leadership and managerial skills; situational awareness; and decision making. As Table 1 shows, each of these categories was further divided into a set of elements that were seen to comprise the broader skill area. This division was intended to aid the assessors during assessment of pilots' performance. Furthermore, for increased clarity in the assessment of non-technical skills, 'word picture' rubrics for poor and good performance were devised for each element within NOTECHS [19]. For instance, poor team building might be evident through behaviour that "blocks open communication," while good team building would be evident when a pilot "establishes atmosphere for open communication" [20]. While NOTECHS was well known within aviation, some airlines had developed their own criteria in an effort to clearly articulate and assess pilots' performance. Despite these various efforts in specifying criteria for use in the assessment of non-technical skills, assessing these skills continues to prove challenging for airlines.

On the one hand, efforts towards enhanced transparency in the assessment of non-technical skills could arguably improve reliability through less reliance on individual, subjective judgements. On the other hand, however, the use of such criteria for assessing complex performance occurs at the expense of judgements made by experts within their field, as statements of criteria cannot replace or replicate these complex judgements. Nor do such statements show the hierarchy of the skills required and the intricate relationship each has with the others [7]. A related argument is that simply specifying detailed criteria does not define a standard against which performance can be assessed [1]. In complex performance-based assessment, assessors must be able to clearly identify the criteria being used, as well as understand the importance of individual criteria in relationship to each other. While complex judgements are necessarily involved in assessing complex performance, clearly articulating the criteria used and their interrelationship can promote both reliability and validity in this form of assessment.

**Table 1. Categories and Elements of NOTECHS [19]**

| Category | Elements |
|---|---|
| **Cooperation** | Team building<br>Considering others<br>Supporting others<br>Conflict solving |
| **Leadership and Managerial Skills** | Use of authority and assertiveness<br>Providing and maintaining standards<br>Planning and coordination<br>Workload management |
| **Situational Awareness** | Awareness of aircraft systems<br>Awareness of external environment<br>Awareness of time |
| **Decision making** | Problem definition and diagnosis<br>Option generation<br>Risk assessment and option selection<br>Outcome review |

## 2.2 Recent empirical research on assessment of pilots' performance

While it has been argued that pilots' performance is judged more frequently than performance in any other profession [21], research shows that improvements to validity and reliability in pilot assessment are still required [22], [23]. A recent empirical research study endeavoured to take into account the progress made in identifying criteria for use in the assessment of pilots' performance, while also addressing some of the limitations [7]. This empirical study was based upon two main arguments. Firstly, approaches to performance assessment that fragment skills into smaller, measurable components do not capture how experts actually make judgements about complex performance. Simply relying on increasingly prescriptive assessment criteria is no guarantee of valid or reliable assessment [24]. Secondly, in unquestioningly adopting a reductionist approach in identifying and articulating pilot performance, the previous research approaches used in aviation were themselves contributing to, and arguably exacerbating, the challenges faced in assessing pilot performance [7]. For this reason, the empirical study outlined in this section adopted a phenomenological approach due to the suitability of this approach for holistically investigating the assessment of pilot performance. More specifically, this study investigated the complex judgements that are made by senior airline pilots during assessment of pilots undergoing promotion to airline captain.

The senior pilot assessors who participated in this study had between 17 and 29 years' experience in assessing pilot. The study demonstrated that these experienced assessors did not distinguish technical from non-technical skills when assessing pilot performance, in contrast to the current approach to assessment within aviation. The research led to the development of a Model for Assessing Pilots' Performance (MAPP), which is illustrated in Fig. 1. As this model shows, the assessors did not view all skills as equal. Instead, the research threw light on a dynamic, complex hierarchy of performance, with some skills seen as essential, while others functioned to maintain or improve these essential skills. Essential skills included: situational awareness, or awareness of what is happening in the surroundings and what is likely to happen; making decisions that are considerate of risk; and flying aircraft within tolerances laid down by the country's aviation authorities or the pilots' particular airline. Adequate performance in these essential skills was required at all times during pilot assessment in order for the performance to be considered satisfactory for promotion. In support of these essential skills, the enabling skills were aviation knowledge, management of crew activities, and communication amongst crew.

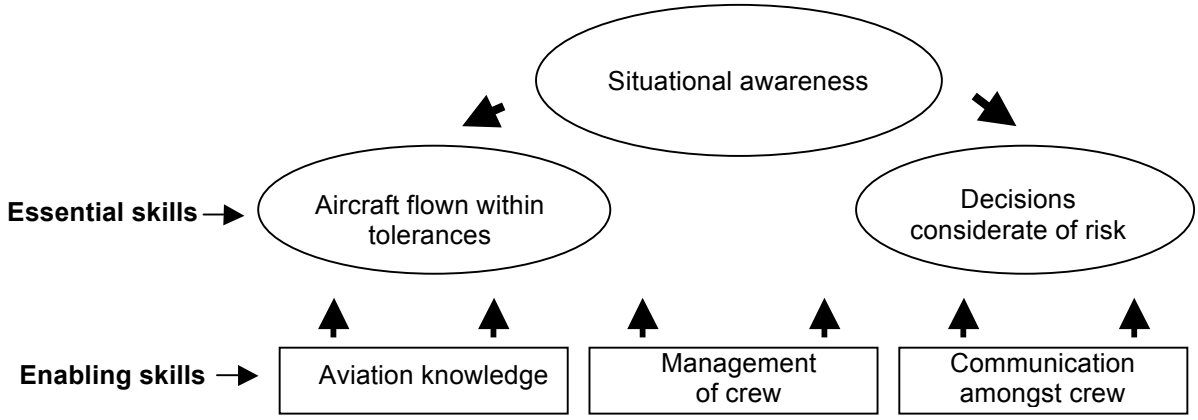


**Figure 1. Model for assessing pilots' performance (MAPP) [7]**

Prior to the development of this model, enabling skills had been regarded as equal in importance to essential skills. This lack of distinction between essential and enabling skills in terms of their importance in flying an aircraft led to a flattening out of the hierarchy of skills that became evident from closely investigating the judgements made during pilot assessment when a more holistic research approach was used. Unlike previous aviation models, the MAPP integrates technical and non-technical skills into a singular model of performance assessment. It provides a means of making explicit the complex performance-based judgements that are made by assessors when they assess pilot performance.

## 2.3 Using the MAPP in complex performance-based assessment

The findings from the study outlined above, in particular the MAPP, have the potential to impact upon both assessment and training in aviation. Three of the implications of this model are discussed in this section. Firstly, the performance that is required by pilots undergoing promotion to airline captain, which previously had not been transparent, has been made explicit. The MAPP makes clear the need to pay attention to essential skills at all times during flying an aircraft, while using the enabling skills to maintain and improve performance. This heightened transparency is potentially of benefit to those being assessed, as well as to the assessors who make judgements about performance. Similarly, increased transparency about what is required in successfully flying an aircraft can contribute to the development of the necessary skills during pilot training, including awareness about the ways in which these skills relate to each other in the complex task of safely flying an aircraft. Secondly, those senior captains tasked with assessing other pilots are provided with a basis for providing targeted feedback in which achievements are identified and ways of improving performance are proposed. This feedback can address performance on the extent to which both essential and enabling skills were effectively used in flying an aircraft or performing in a simulator. In a similar manner, the MAPP provides a means of giving targeted and adequate feedback during pilot training.

Finally, the MAPP can be used to develop improved assessment criteria and to identify the standards to be achieved during performance. The concept of grade integrity from the education literature can assist in this process. Grade integrity has been defined as the extent to which a grade that is awarded "is strictly commensurate with the quality, breadth and depth" of the performance being assessed [24]. Sadler outlines three requirements for achieving grade integrity:

1. Evidence gathered during assessment must be legitimate and credible.
2. Assessment evidence should be sufficiently sound and broad to allow resilient judgements to be made.
3. A grading principle should be used that is theoretically appropriate for determining the level of achievement that is reached. [24]

This approach to performance assessment is central to valid and reliable assessments. In assessing pilots' ability to fly an aircraft, the first requirement above would mean it is necessary to conduct assessments in an aircraft or high-level simulator. A paper-and-pencil test would not be a sufficient form of assessment, although it may be used as one component of such an assessment. To comply with the second requirement, the assessment must be sustained and broad enough for the assessor

to make appropriate inferences about performance. For instance, landing an aircraft on a clear day is not adequate evidence that a pilot can safely land an aircraft in diverse situations. Landing an aircraft at night, in poor weather conditions and with various malfunctions, such as engine failure or no hydraulics, would be required to demonstrate satisfactory command of landing an aircraft.

Finally, the third requirement for a theoretically appropriate grading principle has been lacking in the assessment of pilot performance to date. Until a decade ago, assessment of technical skills has occurred against detailed criteria, with intuitive judgements by individual assessors forming the basis for assessment of non-technical skills. While judgement necessarily plays a key role in assessing complex performance, the absence of an appropriate principle against which grading can occur risks compromising grade integrity. Although some progress had been made in identifying the kinds of non-technical skills that are relevant to pilot performance, the complex interrelationship of skills had not previously been made transparent. The MAPP has contributed to clarifying an appropriate grading principle based on performance on various essential and enabling skills, as well as their interrelationship. It can therefore play an important part in improving grade integrity. Now standards of performance can be more clearly derived through further research, by attending to a single model of performance assessment that the MAPP represents. Challenges remain for the aviation industry - as elsewhere - in designing legitimate and credible assessments, determining sound and sufficiently broad assessment, and using the assessment principle that the MAPP offers in assessing performance in ways that enhance grade integrity.

## 3 DOES THE MAPP HAVE RELEVANCE TO OTHER PROFESSIONS?

There is no doubt that, similar to aviation, all other professions and vocations rely upon unique knowledge and skills necessary to carry out the work. Nurses collecting blood via an intravenous cannula, firemen using breathing apparatuses, engineers designing a bridge and principals managing a school must have sufficient mastery of knowledge and skills that are particular to these occupations. These knowledge and skills comprise one of the means for distinguishing one profession or vocation from another, as well as for determining satisfactory and unsatisfactory performance in each kind of work.

While the emphasis placed on ‘soft skills,’ such as communication and management of personnel, tends to wax and wane within occupational groups over time, these skills are receiving renewed attention within some fields, such as medicine, the armed services, engineering and protective services, including the police, and fire and rescue [18], [25], [26]. In addition, the importance of these ‘soft skills,’ or non-technical skills, is increasingly highlighted when failures or accidents occur. For example, the Three Mile Island and Chernobyl nuclear accidents were attributed to non-technical skills failures [18].

Given that the MAPP incorporates both technical and non-technical skills into a single model for assessment of complex performance, does it have relevance for other professions or vocations? Perhaps the first lesson to be learned from the research that led to development of the MAPP is that there is a need to begin by investigating how assessment of complex performance, such as pilot performance, is actually carried out. This starting point contrasts with suggestions in aviation research that assumed a separation of technical and non-technical skills, as well as further fragmenting these skills into smaller components. While identifying the components that make up complex knowledge and skills is not to be dismissed, beginning from the ways in which practice is carried out is an important principle in this kind of research, as well as in performance assessment.

The MAPP identifies various essential and enabling skills that are important to flying an aircraft safely. The distinction between essential and enabling skills could be valuable to research in other fields, especially where training and assessment of complex performance is being investigated. This distinction also has the potential to be of value for research in a range of fields in which complex performance of work is itself under investigation.

The components of the MAPP and their interrelationship may also have relevance to work in some other professions or vocations. For instance, a school principal must maintain situational awareness about what is happening around the school, including student behaviour, safety and student learning outcomes. In addition, he or she must be aware of the part that teachers and support staff play within the school, as well as the financial position of the school at any point in time. When required to make decisions, the principal must consider financial and other risks associated with the school, as well as the schools key role in educating students. The school must also be managed within the requirements

of the associated education authorities, children's safety and sound educational practice. As do pilots, the principal would need to rely upon extensive professional knowledge and sound management practices, including planning, coordination and control. Furthermore, the principal would communicate with students, staff and other stakeholders in various forms about the functioning of the school.

So, at first glance the MAPP appears to have relevance to at least some other fields. It also has the potential to suggest areas of skill that may be necessary for competent performance on complex tasks. However, it is important to note here that a model developed within one profession cannot simply be transferred to another. It remains an empirical question whether, and to what extent, the components of the MAPP and their interrelationship are relevant to other professions and vocations. Furthermore, whether or not particular skills have an essential or enabling role would also need to be empirically investigated. As noted above, an important starting point in research about complex performance or its assessment is the ways in which this performance is actually carried out in practice.

## 4 CONCLUSION

As noted above, there is a variety of approaches to assessing complex performance. In addition to conventional methods, computers and simulations are increasingly used in training and assessing individuals and teams within a range of professions and vocations. These methods do not remove the need for careful attention to the question of how decisions are made about the standard of performance achieved. In aviation, expensive simulators and real aircraft are used to replicate realistic scenarios. Despite these improved techniques, challenges have remained in making judgements about pilots' performance.

A recent research study in aviation sought to overcome the limitations of previous reductionist research in order to develop a more robust approach to assessing pilot performance. This research empirically investigated current practice in how experienced senior pilots assess pilot performance, giving rise to the development of the MAPP. Based on this research, a theoretically appropriate grading principle has been developed, which was lacking in the assessment of pilot performance to date. The MAPP has enabled each assessment criterion to be identified and viewed in relationship to each of the other criteria. Also, the model means that assessment is more transparent, for those being assessed, and those conducting the assessment. Furthermore, the MAPP can assist in debriefing during the training or assessment of complex performance, and can lend itself to the development of assessment tools and training that target the required performance. This paper has also identified ways in which the development of the MAPP and the model itself are potentially useful beyond aviation. The lessons from this study within aviation may have relevance to other vocations and professions.

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