''You have control, AI has control'' the 2030 Flying Instructor

Helen M Gardiner
Thales UK Ltd.
Crawley, W. Sussex, UK
helen.gardiner@uk.thalesgroup.com

ABSTRACT

In as little as 10 years, combat aircrew will manage a complex array of airborne weapons systems, often operated remotely or even autonomously. Future platforms will be optimised to take all but the most complex tasks and decisions away from the operator. Systems management; analytical problem solving; and timely, effective, decision making will be the key competences of the air-minded war-fighter, be they controlling weapons systems from the air, on the ground, or from space.

So what of the flying instructor? As pilot performance focuses more on mental agility, flexibility, adaptability, and speed of mental processing, what will be the role of the future flying instructor? Can technology provide the means for replacing the human instructor?

Drawing upon published research and the author's experience in the Royal Air Force and UK Defence Industry, this paper explores the aspects of human performance relevant to future combat aircrew and determines whether Artificial Intelligence (AI) and new training technologies can provide the solution to their future training needs. It also explores the potential for technology, including AI, data analytics and biometrics, to support the training of cognitive behaviours.

The author advocates a New Instructional Paradigm, where technology plays a greater role, allowing the human instructor to focus on complex cognitive behaviours. This approach requires the use of non-intrusive objective measures of cognitive performance, and powerful AI-driven data analytics, to better inform the instructor and add real value for the trainee. Instructors' competences will need to evolve from experienced operator to performance coach, equipped with a deeper understanding of human cognitive science. This integrated approach maximises the value from technology and data, whilst maintaining the element of human experience, to provide a comprehensive, evidence-based assessment of a trainee's performance and potential.

ABOUT THE AUTHOR

Helen Gardiner served 23 years as a pilot in the Royal Air Force, becoming the first female Tornado F3 operational pilot in 1995. Following tours as a Qualified Flying Instructor on both the Tucano and Tornado F3, she was promoted and appointed as 22 Training Group Transition Manager for the UK Military Flying Training Service Advanced Fast Jet Training Capability in 2004. She returned to flying as Officer Commanding 72 Squadron (Basic Fast Jet Training (BFJT) Squadron at RAF Linton on Ouse) in 2009 where she was responsible for the delivery of the BFJT course to UK and overseas trainee fast jet pilots.

In 2013, Helen joined Thales in the UK and is currently Head of UK Military Training Services, where she is responsible for the delivery of the Royal Air Force's High G (Centrifuge) Training Service Contract along with the management of the Thales Typhoon Synthetic Maintenance Teams at RAF Coningsby and Lossiemouth and the A400M Synthetic Maintenance Team at RAF Brize Norton. Helen is also leading the development of the Thales Aircrew Training capability, a new approach to enhancing human performance through the innovative use of modern learning technologies, data analytics, and Artificial Intelligence.

''You have control, AI has control'' the 2030 Flying Instructor

Helen M Gardiner
Thales UK Ltd.
Crawley, W. Sussex, UK
helen.gardiner@uk.thalesgroup.com

INTRODUCTION

To become a fighter pilot is still the aspiration of many young men and women, but the environment in which they operate and the physical and mental demands of the role are very different now, even compared with only 20 years ago. Learning to fly an aircraft such as the F-35 takes on a different dimension as many of the traditional handling skills become automated, freeing up pilot time and capacity to cope with the exponential increase in systems and information presented to the pilot. A USAF F-35 pilot, Major Valerie "Twitch" Wetzbarger was quoted as saying "The transition from a 4th Gen to a 5th Gen fighter was like learning how to drive an automatic car from a manual" (Shiner, 2019, para 19). This observation offers nothing particularly unexpected, the shift from flying to operating skills has been happening since the earliest days of flight. However, the rate of change is accelerating; physical motor skills are being handled by the aircraft itself whilst cognitive skills become ever more the focus of a pilot's capability.

Figure 1. *One of the UK's first F-35B Lightning II aircraft over Eglin Air Force Base, Florida*[1]

Training combat aircrew has already shifted focus towards the greater use of synthetics which have enabled pilots to experience more immersive and realistic training prior to even setting foot in modern fighter aircraft. Networked Full Mission Simulators, supported by a range of lower fidelity devices, allow significantly more training to occur on the ground, saving cost and time. But this is only the start of the journey into exploiting digital technologies as synthetic training becomes the major element of future training courses. Lenny Genna, President of L3 Link Training & Simulation sees developing technologies "as removing several key training constraints – they will improve the way that human instructors engage in training. They will allow computers to automate those processes that are entirely objective. You can ingest that expertise into the computer and reduce the live instructor requirement, letting automated teaching and assessment objectify the event." He also predicts that Artificial Intelligence (AI) "ultimately will reduce the human role in training and simulation" (Adams, 2019, p. 15).

These technological developments have been welcomed at a time when there is a significant military pilot shortage across the globe. The limited number of instructors with recent and relevant experience of new generation aircraft has been a further challenge. Taking pilots from the front line in order to train novices depletes front line capability but without this sacrifice, the training pipeline is not sufficiently resourced to train the next generation of pilots. In 2019 the US Department of Defense (DoD) faced a shortfall of 3000 pilots (US Department of Defense, 2019), the most acute challenges being fighter pilots and instructor pilots. A UK Report into Military Flying Training (UK National Audit Office, 2019) also cited the lack of qualified instructors as a key reason for the lack of UK trained military pilots. Concerns have also been raised about the sustainability of the current RAF instructor training system.

[1] MOD Crown Copyright (2014). Published under UK Open Government Licence (http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/)

Gardner (2019, para 4) stated:

> The RAF has struggled for some time to retain qualified instructors, but until SDSR 2015[2] the problem was disguised by the decline in the requirement for frontline pilots. If the current cohort of trainees only reach the frontline at the end of their 20s, and their return of service is 12 years, then they will have only a couple of flying tours before they leave. How then does the RAF, alongside the Navy and Army, generate and retain flying instructors? This is the critical issue of the current crisis and one that should be exercising the minds of RAF leaders; military flying instructors are the critical enabler of a professional flying training system.

There are several issues within this vicious circle which highlight the importance of managing training not just from the perspective of the trainee but also the instructor. It also explains the recent focus on the use of AI to support training in order to reduce the reliance on human instructors. The fundamental question is therefore how to introduce technology effectively in order to best support the training systems of the future. This paper considers how the use of data and digital technologies can improve pilot training from an instructional perspective and investigates several key issues:

- How have developments in the objective measurement of human performance allowed data analytics and AI to provide valuable information to the trainee and instructor?
- With a growing number of data sources offering the potential to assess a trainee's performance, how should this information be used to make the instructor's role more efficient and effective rather than simply overwhelm?
- AI is often used freely as the answer, but what does it actually mean in the context of pilot training and how is it best employed?

TRAINING COMBAT PILOTS IN THE AGE OF DATA

Pilot training has evolved over many decades to take account of advances in platform technologies and an increased understanding of human factors associated with flying. Future combat pilots are expected to operate in a very different environment to previous generations, as the number of platforms reduces, the technical complexity increases, and the role expands to meet the demands of multi-dimensional warfare. Defining these key new areas of knowledge, skills, and attitudes will be vital if training is to be effective. The increase in aircraft automation and ever growing importance of managing the human-machine interface creates new opportunities and challenges. Training systems need to keep pace with the new demands placed on pilots from more advanced combat aircraft, whilst also exploiting innovative and appropriate digital enabling systems to deliver efficient and effective training outcomes.

Impact of Automation

Automation of aircraft tasks has been a growing trend in order to reduce pilot workload. Use of autopilot is widespread with pilot workload being more focused on monitoring of systems and being able to intervene if required due to technical failure or in a scenario where complex decision making is required. This hands-off approach has created its own challenges, where the competence of pilots to be able to fly the aircraft is reduced through lack of practice and the startle effect can result in human error, where pilots held at relatively low arousal states are required to step in quickly to resolve a potentially difficult situation. For combat pilots these issues are perhaps less relevant than for civilian airline pilots, due to the requirement for more active engagement in the flying task and increased arousal levels on most sorties. There are exceptions, for example long distance trails, where a relatively benign sortie is interrupted with short periods of intense concentration for refuelling activity or to deal with an unexpected emergency.

There remains, at least for the current generation of combat aircraft, a requirement to manually fly the aircraft. As such, early stages of flying training are likely to continue to teach fundamental handling and piloting skills such as navigation at least for a few more years. However, this training requirement may start to reduce further as elementary aircraft platforms become more complex in terms of systems and include basic autopilot functionality, thereby reducing the emphasis of traditional training to simple reversionary skills. With pure aircraft handling becoming less of a focus, the instructional requirement will be to support trainees even more in the development of transferable cognitive skills, enabling pilots to manage multiple systems and multi-sensory inputs whilst also demonstrating effective situational awareness and decision making behaviours.

Cognitive Performance Assessment

In order to objectively assess cognitive performance, the requirements of a combat pilot need to be analysed in terms of

[2] UK Ministry of Defence Strategic Defence and Security Review 2015

a specific task analysis. Rasmussen's Skill-Rule-Knowledge (SRK) behaviour model (Rasmussen, 1983) suggests that an individual's approach to tasks corresponds to different behaviours and this taxonomy may hold clues as to how to best focus the use of automation in training.

- *Skill-based behaviour* occurs in highly familiar contexts when all the required cues are present for the individual to carry out the task without conscious control. Riding a bike and driving a car are common examples, as are many pilot-handling activities once experience is gained.
- *Rule-based behaviour* involves a sequence of actions typically controlled from a rule or procedure, in a familiar setting, with only a minimum amount of additional information required in order to action the task. An element of conscious monitoring is still required if actions are to be performed without omissions and in the right order. Examples utilise procedural approaches such as pilot checklists.
- *Knowledge-based behaviour* is the most demanding and used for unusual situations. Individuals require conscious effort to obtain sufficient understanding of the situation, and assess potential solutions in an unfamiliar context, before determining their course of action. This places significant mental load on the individual compared to skill- or rule-based behaviour. The example of US Airways Flight 1549 landing on the Hudson is used to illustrate the high level of uncertainty and need for the pilot to develop a *new* mental model.

Cummings offers an extension of Rasmussen's model to include uncertainty and expertise which shows the relative strengths of computer versus human information processing. He explains that "Expert behaviours sit at the top of the reasoning behaviours, which build on knowledge-based reasoning. Expertise leverages judgment and intuition as well as the quick assessment of a situation, especially in a time-critical environment such as weapons release." (Cummings, 2017, p. 6) He added "In humans, the ability to cope with the highest situations of uncertainty is one of the hallmarks of a true expert, but in comparison such behaviour is very difficult for computers to replicate." (Cummings, 2017, p. 6) In the example of US Airways Flight 1549, no autopilot could have replicated the pilot decision making as this was clearly in the realm of significant uncertainty.

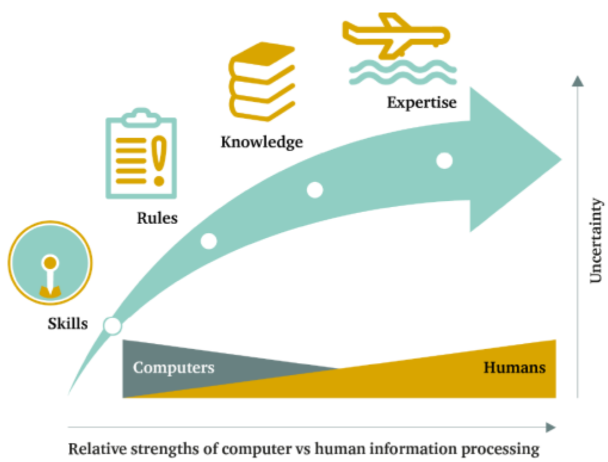

Figure 2. *Cumming's extension of Rasmussen's Model to include Uncertainty and Expertise* (*Cummings, 2017, p. 5*)

Cockpit automation has therefore focused on replacing skill- and rule- based tasks, as they are repetitive and the easiest to replicate using mathematical representations. Automation of these tasks also aims to further improve safety by reducing the risk of human error due to complacency, where experienced operators come to rely on unconscious action. In training, technology has been primarily focused around the use of machine-based learning to support development of skill- and rule-based behaviours. Self-paced learning on part-task trainers such as Hands-on-Throttle-and-Stick (HOTAS) is a simple example of creating a low-cost training solution for developing skill-based behaviour. For rule-based behaviour, an example is the use of Virtual Reality (VR) technology to allow trainees to learn and practice checklists. Performance can be directly assessed against the checklist content, with a tutorial element offering direction on the correct flow and assessment scores based on practice sessions; an example is at Figure 3. Gamification of these types of learning devices also aims to increase trainee engagement and motivation in the learning process. They also offer the opportunity for adaptive learning techniques to be applied to focus training on individual need.

Figure 3. *Rule – Based Training Technology*
Thales VR Checklist Trainer - Demonstrated at Vertical Flight Expo London 2019

While these technologies reduce the requirement for the human instructor to some extent, to make a significant impact on the current shortage, technology will also need to replace more aspects of knowledge-based behavioural training. This will require innovative solutions to support the objective assessment of cognitive skills, often termed Airmanship in an aviation context, and the measurement of workload to monitor mental capacity.

Airmanship Assessment

Kern defined Airmanship as "the consistent use of good judgment and well-developed skills to accomplish flight objectives. This consistency is founded on a cornerstone of uncompromising flight discipline and is developed through systematic skill acquisition and proficiency. A high state of situational awareness completes the airmanship picture and is obtained through knowledge of one's self, aircraft, environment, team, and risk" (cited in Skybrary, 2020). The RAF Flying Manual (RAF Central Flying School (CFS), 2015) defines the RAF Airmanship Model, which is used throughout RAF flying training units to support assessment of the key elements of Airmanship. This decision-making model, based on Col John Boyd's 'OODA Loop' - Observe, Orient, Decide, Act, is termed the **R**ecognise **A**nalyse **P**rioritise **D**ecide **A**ct (**R**eview) loop (RAPDA(R)). While this and other similar models offer guidance as to how effective an individual may be performing in terms of Airmanship, this assessment is generally norm-based against a trainee's peers, or the level of performance that would be expected at that point in training, as opposed to criteria-based where a specific level of defined performance is available for comparison.

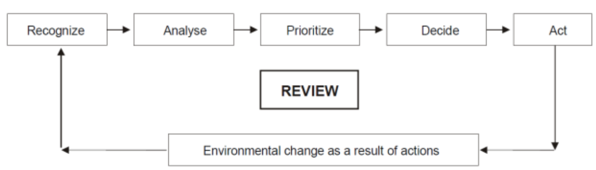

Figure 4. *RAF Central Flying School Airmanship Model* (RAF Central Flying School (CFS), 2015, p.4)

The model uses several key areas of assessment which are inherently difficult to assess objectively.

- Situational Awareness.
- Decisiveness.
- Communication.
- Resource Management.
- Mental Performance.
- Spare Mental Capacity.

Of these, Situational Awareness (SA) and Workload, referred to in the RAF model as Spare Mental Capacity, have been the focus of significant research. If studies provide the means by which to capture sufficient, relevant, and objective data, this may enable future machine-assessment of trainee performance in some knowledge-based tasks. However, the objective measurement of both SA and Workload remains a challenge as described below.

Measuring Situational Awareness

A variety of models have been created for SA including that of Endsley (1995) who defined SA as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." (cited in Thanh Nguyen, 2019) Several methods have been used to try to measure SA (Thanh Nguyen, 2019) all of which create significant challenges for use in training:

- *Freeze Probe* – stopping the simulation to assess SA at a specific point in time against a set of criteria. This allows a real time assessment rather than rely on post event memory but is intrusive.
- *Real Time Probe* – assessing SA at a specific point in time without stopping the simulation but is difficult in dynamic situations and adds to trainee workload if they continue to operate while being questioned.
- *Post event self-assessment* –a less intrusive measure but is subjective and relies on the ability of the trainee to assess their own performance objectively. For less experienced operators this is unlikely to be the case.
- *Observer rating* –the instructor uses their knowledge of expected trainee performance and wider aviation experience to assess SA.
- *Performance measures* – assessing the objective achievements of the flight. However, success may simply be due to combination of other factors when the individual's SA was actually relatively poor.
- *Process Indices* – Eye Tracking is an example of a measure that can determine where a trainee is focusing their attention while performing a task. However, a trainee may be *looking* but not *seeing*.

Workload Assessment

Individuals performing tasks under low stress and low workload conditions (such as monitoring systems) and tasks under high stress and high workload conditions generally perform less effectively. It is therefore of major importance in safety critical environments to understand pilot workload in order to predict and reduce errors in human performance. Martins (2016) considered the challenge of measuring workload and described three broad categories of measures:

- *Physiological measures* such as heart rate variability, brain activity, and pupil size offer some objective analysis but are intrusive. Eye tracking can offer some potential, where the length of fixation on a specific instrument can indicate the difficulty in interpreting the information presented.
- *Performance-based measures* can be used to give an assessment of task accuracy or provide information on the number of tasks being conducted at the same time. Using a baseline task performance level may allow greater objective analysis of workload when an additional task is introduced (secondary task methodology).
- *Subjective measures* use a range of methodologies to assess mental workload, but most are applied after the event and as such are reliant on memory.

Use of Biometrics for Objective Performance Measurement

While objective measurements of SA and workload have been the subject of significant research, there is limited evidence of practical use within military flying training due to the challenges highlighted in the previous sections. However, the use of biometrics is now becoming a real focus for training technologies in sectors where improvement of physical and cognitive human performance is of significant importance. Elite sports monitor individual's biometrics as part of rigorous training regimes and this application has evolved to allow wider society to use simple non-intrusive data analytics for their own exercise training. Motorsport is exploring the use of biometric gloves and eye tracking to monitor the stresses on a driver during a race in order to improve safety and performance (Robertson, 2017).

Recent advances within the aviation training sector have used a combination of biometrics and synthetic training data to allow the relative measurement of pilot attention across a variety of cockpit tasks. Innovative training capabilities such as the HuMans System (Thales, 2019), provide a more comprehensive profiling of pilot performance and workload through the use of contextualised analytics and biometrics (including eye tracking). This data driven technology, combining objective and subjective measures, provides the instructor with an enhanced understanding of trainee performance in real time and for use in after-action reviews.

Figure 5. *HuMans - Human Performance Monitoring System*

FUTURE INSTRUCTOR – HUMAN OR MACHINE?

Machine-based learning and assessment

Flying instructors are required to carry out a range of tasks in order to impart knowledge and assess the performance of their trainees. With the aim of reducing the reliance on human instructors, the logic would follow that skill-based tasks should be the easiest to assess objectively by comparing actual trainee performance against a mathematical representation of the ideal using specific criteria (for example an autopilot flight profile). Synthetic training sorties could then utilise a *virtual instructor* to give feedback on performance and corrective action in real time or as part of the scenario debrief. Similarly rule-based tasks may again be modelled in terms of a checklist or simple 'if x then y' scenarios, where data can be analysed in order to objectively assess performance of the task against known criteria. Individualised learning may then be made possible across a wide range of tasks without the need for a human instructor to be involved, creating opportunities for adaptive and self-paced learning.

The future dilemma however is that while these types of tasks are more easily assessed by machine-based algorithms, the relative importance or requirement for pilots to carry out these tasks will ultimately reduce as aircraft operations further automate to reduce pilot workload. Greater emphasis on knowledge-based tasks, where analytical and intuitive reasoning are dominant, requires even more human involvement in training and assessment due to the inability of the machine to be able to replicate the complexity of these decision making processes. The widely asserted answer to providing training for more complex tasks is AI; but what does this mean in the context of flying training?

Artificial Intelligence

Cummings (2017, p.2) stated that "There is no one commonly agreed definition, even among computer scientists and engineers, but a general definition of AI is the capability of a computer system to perform tasks that normally require human intelligence, such as visual perception, speech recognition and decision-making. This definition is, however, inherently oversimplified, since what constitutes intelligent behaviour is also open to debate". AI relies on the ability to collect large volumes of data in order to gain value through the use of powerful, intelligent analytics and mathematical algorithms. The collection of training data for all pilots and other aircrew throughout their flying careers offers a huge potential for system and individual learning efficiencies. The initial benefits of AI are therefore most likely to be found in the use of powerful analytical tools, offering the ability to apply root-cause analysis and provide instructors and Training Managers with evidence-based trends for individuals and the wider trainee population.

The use of AI as a virtual instructor to *replace* human involvement within safety critical environments is a more complex and challenging area. Concerns lie primarily around reliability of the autonomous system and trust in the system being able to provide appropriate responses in a transparent and consistent manner. Replacing the human instructor in the training and assessment of a pilot's competence removes a layer of safety governance and is likely to come under significant scrutiny. Knowledge-based behaviour is inherently difficult for computers to replicate and without this ability, the use of AI to train and assess cognitive performance is likely to remain extremely limited. As Cummings (2017, p.7) concluded, "replicating the intangible concept of intuition, knowledge-based reasoning and true expertise is, for now, beyond the realm of computers. There is significant research currently under way to change this, particularly in the machine learning/AI community, but progress is slow". The more immediate benefits lie in the use of AI-driven algorithms to support skill- and rule-based training and powerful analytics of objective and subjective data to enhance instructor assessment.

Data-Enhanced Instructor Assessment

Despite the many challenges of measuring human performance objectively, there are significant benefits from exploiting data from modern synthetics. However, simply providing more data at the point of training delivery shifts the challenge of managing workload from the trainee to the instructor. It also raises the question as to *which* data is the most important to capture. The answer is not straight-forward; data that at first appear insignificant may generate new insights when used within the context of a wider data picture. Effective interpretation of the data may also require new skills and training for the instructors themselves. Just as it is fundamental for the design of the aircraft itself, the effective human-machine interface between the instructor and the data-enhanced synthetic training device is essential to the successful outcome of the training task.

As previously highlighted, data analytics can more easily support training for skill- and rule-based tasks without the need for the instructor to continuously monitor all of these variables. Instructors could then focus on monitoring cognitive behaviours where deeper analysis and assessment of the elements of situational awareness could be applied with supporting evidence from biometrics and other non-invasive measures. As more data are gathered across a wide range of trainees at all stages of training, Airmanship could potentially be measured and norm-referenced automatically, again reducing the workload and experience needed by the instructor to give an informed assessment. Tracking key measures of performance across time also has the potential to allow early recognition of potential. This requires correlation between early stage cognitive performance and longer term selection for specific roles such as combat pilots, and offers the potential to select and stream pilots much earlier, based on selection tests for cognitive skills, saving significant cost and time in training these individuals.

The collection, long term storage, and use of personal data within flying training require serious consideration of security, ethics, and digital trust. Ensuring that data which can determine an individual's future prospects and opportunities are secure, unambiguous, and reliable is central to the effective, safe use of data in aviation training. Transparency for trainees is also important if they are to have confidence in the decisions and outcomes of their training experience. A final consideration is that whatever the technical solution looks like, people will still be liable and responsible for the behaviour and consequences of the solution in operation. In other words, whatever AI or data-driven solution is offered, the responsibility will ultimately still lie with the Training System Owner for assessing whether a trainee performance meets the standard and is safe to operate an aircraft. As such, they will need full confidence in the system, the data, and its outcomes.

Generating Mental Models

Operational training focuses more on the ability to manage systems and make decisions in a complex airborne environment. Much of this cannot be taught; it is the exposure to different and uncertain environments in order to build new mental models. The instructor role, particularly in a synthetic environment, is to create these different scenarios and assess performance against key objectives (mission success criteria) whilst also assessing situational awareness and mental capacity (how well did a pilot achieve success). Synthetic training at all levels of complexity (be that training for individual platform specifics or in more collective networked scenario) are ideal for generating mental models as it allows consistent approach for all trainees and ability to replay events to identify key learning points. The issue remains that the range of scenarios may be constrained by instructor experience; unless instructors have significant knowledge of both role and platform, their ability to continuously develop and enhance training profiles may be limited.

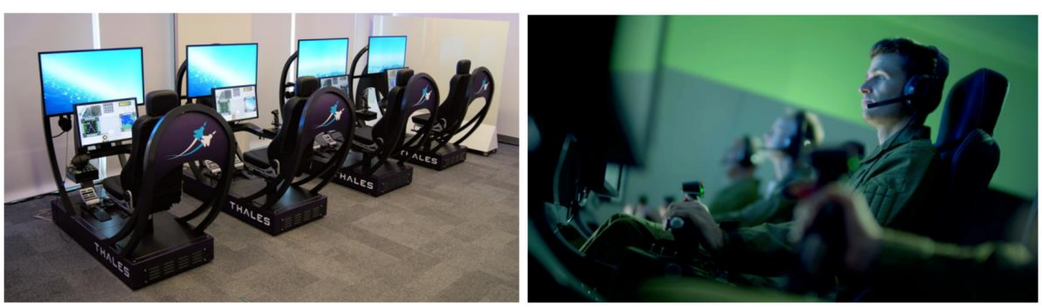

Figure 6. *Using synthetics for complex collective training (Thales, 2020)*

Live flying offers the opportunity to experience uncertain and random events. These provide the basis for significant expansion of mental models and learning for the individual, and across the wider military and civilian aviation sectors.

Only by experiencing something that has not been considered previously, can significant progress be made to address likely human errors or technical faults. For example, the investigation of the cause of the Air France flight 447 crash over the South Atlantic in 2009 has generated significant training requirements for pilots in upset recovery drills.

Considering the anticipated reduction in live flying hours for combat pilots, simulation scenarios will need to be more complex and wide ranging to ensure pilots train for the unexpected. Random environmental factors, emergency scenarios, or threat presentations may be better generated by the system rather than the instructor in order to ensure the scenarios do not become too constrained. Technology may be best placed to generate these scenarios as long as the boundary of this activity is controllable, to ensure training is realistic, transparent, and challenging. AI driven Computer Generated Forces (CGF) is another area where technology is allowing a much more complex generation of opposing forces for synthetic training. Using an innovative technique in machine learning, the creation of Genetic Fuzzy Logic Trees, Psibernetix has developed a technology named "EVE" which has been utilised in defence and other mission critical sectors such as medicine (Psibernetix, 2020). This type of technology offers the opportunity for future use of AI in more complex synthetic training environments by enabling computer-generated opposition forces to train, learn, and perform independently, without the need for instructional time in creating each specific training scenario. While the AI is mathematically deterministic, it is able provide a much wider range of behaviour patterns due to its observation and reaction to the environment around it. It is therefore extremely unlikely that the same scenario repeated will result in a similar outcome, enabling significant variety of training content.

The Digital Twin Combat Pilot

Despite current limitations, developments in technology and artificial replications of human behaviour may ultimately allow future generations of combat aircraft to be flown by AI. Unmanned combat aircraft are already in development and whatever human element that remains may be replicated as a digital twin, an AI representation of the ideal operator performance to act as a comparator for assessing future operator performance. This concept has been described by Tim Davies, Strategy Director for Aeralis, who describes the digital twin in training as something "which represents the model war-fighter that a student needs to emulate, and which the student then tries to match by working towards making their digital record of flying and combat performance equal to that of the twin" (Davies, 2019, p.1). This still raises the question of how to design the perfect pilot and develop and train the model war-fighter itself, as the requirements of the role ever change and evolve. At some point, perhaps the training of humans in combat flying will no longer even be necessary and the perfect digital twin will be able to replace the human. Elon Musk has controversially said that the age of the fighter pilot is coming to an end and that the human is now the limiting factor in a cockpit, not the advantage (Kennard, 2020). However, having a human in the cockpit, particularly until inherent latency challenges are resolved, is likely to keep the combat pilot employed for a few more years to come.

SELECTING AND TRAINING THE INSTRUCTORS OF THE FUTURE

Experienced Operator to Performance Coach

Traditionally an instructor was someone who had a significant level of experience in both role and on the specific aircraft type to deliver flying lesson plans and mentor trainees at all stages of training. Early training is the basis of assessing not just overall performance but more importantly *potential*. Instructors are not simply training individuals to be the best T6 or Hawk pilot; they want to know if they are capable of transferring the skills they have learned and continue to learn at the appropriate rate to fly a combat aircraft such as F35. This requires some understanding throughout the training system of the requirements of the end-game and the required rate of learning. As the rate of change in requirements for operating modern combat aircraft accelerates, the platform and role expertise of instructors may lag behind those of traditional instructor cadres. There is likely to be an enduring requirement for some level of subjective assessment, so, when there are so few individuals with experience of flying a Gen V aircraft, how do instructors support trainees of the future?

Lieutenant JG Thorys Strensrud USN when referring to learning to fly an F-35 said, "it definitely was a challenge to learn….The basic skills come pretty quickly, in two or three flights. The most challenging part is how much information the jet presents to you and focusing on the right things at the right time. Over time, you kind of find the best way to process the information. I can't think of another experience I've had that's quite like that". (Shiner, 2019, para 13) This implied experimental and self-taught approach to learning is far removed from the clearly defined training objectives of traditional flying courses. In many ways the approach that a trainee combat pilot may need to take in future in order to increase his competence is almost that of a test pilot, who applies his wider knowledge of aviation principles to a new aircraft rather than learn specific skills for a particular aircraft type. This may change the emphasis of the instructor's competence from experienced operator to performance coach.

Cognitive Function Improvement

As the human instructor is still likely to be required to support the training and assessment of knowledge-based behaviours, instructors themselves may need training to be effective in their future roles. Without significant experience of new generation aircraft, interpretation of data or specific knowledge in human sciences, instructors may find the new environment a growing challenge. More objective data may help with assessing trainee SA and mental workload but does not offer all the answers as to why a trainee failed to perform well or offer strategies to help them improve.

The RAPDAR model breaks down elements of decision making into specific elements to better allow the instructor to focus on resolving a problem. For example, if the outcome was poor, was that because the trainee did not have sufficient information, did not effectively interpret the information, or simply not act on their (correct) decision? Providing appropriate coping strategies for cockpit workload will play a much greater part of an instructor's competences but what if a trainee's ability to learn is fundamentally dependent and limited by innate cognitive capability? Development of cognitive function is another significant area of research especially across differing age ranges. If it is believed that cognitive function cannot be significantly improved, even with appropriate interventions, there may again be more emphasis on selection of individuals much earlier in the training system. Selection tests, focusing on systems management skills, cognitive abilities and learning styles, may support early selection of future combat pilots in a similar manner to that of astronauts. Similarly, if intervention strategies are proved successful in improving cognitive function, the focus for training may shift more radically to these types of strategies throughout the training journey.

A New Instructional Paradigm

It is clear that technology will play a much greater part of any future training system to enable machine-based learning and the use of AI where appropriate. Trainees will require greater competence in cognitive skills and there may be greater emphasis on early selection testing in order to have confidence that individuals have appropriate innate capabilities. Skill- and rule- based behaviours are most likely to be transferred to the virtual instructor while competence in knowledge-based behaviours are generated through complex synthetic scenario developments, ensuring trainees can manage uncertainty and the ability to generate effective new mental models when dealing with random events. The important issue within this new paradigm is to identify where the human instructor can add real value.

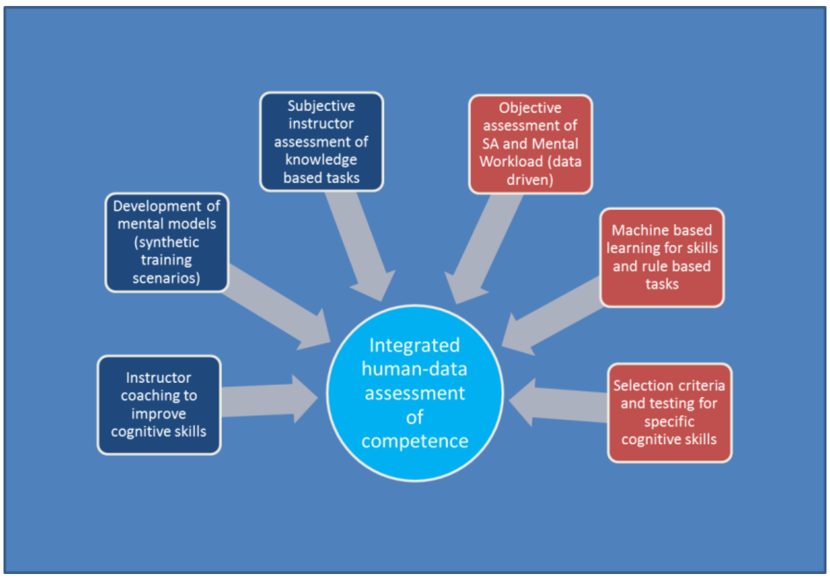

Figure 7. *A New Instructional Paradigm*

To be effective, instructors need to be competent in analysing complex data and understand human cognitive behaviours to best facilitate learning. There may be significant benefits in automating certain aspects of training, particularly those where the outcome can be replicated by an algorithm to identify errors and offer corrective action. However, replacing the abilities of an experienced instructor to reconstruct a complex mission, utilising evidence from several data sources to highlight key learning points, in a structured and concise manner, will remain a valuable human skill.

SUMMARY AND RECOMMENDATIONS

The role and requirements of a modern combat pilot are significantly different to those of even Gen IV aircraft. Training systems are starting to consider the use of machine based algorithms and AI to support the training and development of future pilots, but this has been driven not simply by innovation but by a lack of appropriately experienced instructors. There is a danger that in the rush to solve a resource problem, the future needs of instructors are not fully considered and technology drives solutions without necessarily considering the importance of the human element. In particular, as automation reduces the need for skill- and rule-based tasks, the emphasis will shift more radically towards knowledge-based performance including the ability to generate effective SA and operate complex systems with sufficient spare mental capacity. This paper set out to consider how the use of AI can improve pilot training from an instructional perspective and has highlighted the complexities of using technology to train and assess knowledge-based performance.

In addressing the question of objective measurement of human performance, there is a significant amount of research particularly around SA and workload but perhaps less evidence in terms of clear technological applications. Biometrics appears to be leading the way in providing non-intrusive objective measures, which, when presented in a contextualised form, can offer significant insight into the real time performance of an individual in high stress environments.

The ability to capture additional data sources with which to assess a trainee's performance and potential is also a real opportunity to further expand the role of AI within flying training. However, this also presents a challenge to the instructor in terms of how much information they can, themselves, assimilate. Systems need to be integrated and contextualised so that biometric and systems data can be interpreted as a whole rather than individual elements. Using AI not specifically to replace a human instructor, but as a way of assimilating huge amounts of data on the trainee's current and past performance, comparing this against historical peer results, and then presenting the information to the instructor in real time, could lead to a major step-forward in the development of human pilot performance.

Technological progress in this area depends on the maturity of several key data-driven capabilities:

1. Non-intrusive measures of objective data to support traditional subjective assessment.
2. The creation of a large enough data set to allow real value to be derived in terms of trends and correlations for the individual trainee and wider training system.
3. Powerful AI-driven analytical tools which provide transparent, understandable, and ethical[3] information to instructors to support future training and assessment.

In order to best employ AI alongside human instructors within the context of flying training, developers need to ensure that systems are not just about generating data but about creating real added value whilst ensuring an effective human-machine interface for the instructor as well as for the trainee. The instructor will need to be adept at interpreting the data and understanding how to integrate this evidence efficiently into a wider performance assessment of the trainee. The greater shift towards cognitive performance will also require a different approach to selecting and training instructors where human performance coaching becomes a more important competence than simply being an 'experienced operator'. This will require more in the way of training for instructors in the understanding and application human performance science. Creating a new instructional paradigm will support instructors of the future to combine meaningful data from technology sensors, AI and their experience-based observations of performance, in order to bring real advances in evidence-based assessment of trainee progression and potential.

Most importantly, developing a clear understanding of what makes an effective future combat pilot, their core cognitive skills, traits, learning style, and even personality profile is essential if selection criteria and training requirements are to be clearly articulated. This profile may differ significantly from the traditional fighter pilot profile but is fundamental if it is to inform technology development and human science research in creating the most effective, efficient training system for the future. Equipping the instructors with this understanding, providing them with rich sources of data and enhanced human performance coaching skills, will enable them to better select and train air-minded war-fighters and maximise the operational effect of any future air combat system.

[3] Thales definition of 'TrUE AI'

REFERENCES

Adams, R. (2019, March 5). Trending: AI-Enabled Adaptive Training – The MS&T Forecast. *International Defence Training Journal - MS&T, Issue 1.2019*, 15. Retrieved from Military Simulation & Training Magazine: https://militarysimulation.training/articles/trending-ai-enabled-adaptive-training-the-mst-forecast/

Cummings, M. L. (2017, January). *Artificial Intelligence and the Future of Warfare - Research Paper.* Retrieved from Chatham House: https://www.chathamhouse.org/sites/default/files/publications/research/2017-01-26-artificial-intelligence-future-warfare-cummings-final.pdf

Davies, T. (2019, Oct). *Adding Gamification to the Training Syllabus for Fighter Jet Pilots*. Retrieved from Aeralis: https://aeralis.com/wp-content/uploads/2019/10/AERALIS_Gamification_QA_signedoff.pdf

Gardner, S. (2019, March 12). *UK Military Flying Training Heading for the Cliff Edge*. Retrieved from RAeS: https://www.aerosociety.com/news/uk-military-flying-training-heading-for-the-cliff-edge/

Kennard, P. (2020, February 29). *Elon Musk Shoots Down The Fighter Pilot's Future. Is He Right?* Retrieved from Forbes: https://www.forbes.com/sites/paulkennard/2020/02/29/elon-musk-shoots-down-the-fighter-pilots-future-is-he-right/#52c1ae5c1d0b

Martins, A. P. (2016). A Review of Important Cognitive Concepts in Aviation. *Aviation*, 68-69.

Psibernetix. (2020, Jun). *Projects*. Retrieved from Psibernetix: http://www.psibernetix.com/projects/

RAF Central Flying School (CFS). (2015, November). Flying Manual (AP3456) Volume 6 Aviation Medicine Chapter 3. Royal Air Force.

Rasmussen, J. (1983). Skills, roles, and knowledge: Signals, signs and symbols and other distinctions in human performance models. *IEEE Transaction on Systems, Man, and Cybernetics SMC.*, 258-259.

Robertson, J. (2017, November 21). *5 ways biometric technology could improve motorsports*. Retrieved from Red Bull: https://www.redbull.com/gb-en/biometric-technology-in-motorsports

Shiner, L. (2019, April). *F-35:What the Pilots Say*. Retrieved from Air&Space Magazine: https://www.airspacemag.com/military-aviation/f-35-faces-most-critical-test-180971734/

Skybrary. (2020, Jun 10). *Airmanship*. Retrieved from Skybrary: https://www.skybrary.aero/index.php/Airmanship

Thales. (2019, December 19). *HuMans, Human Performance Monitoring - Thales*. Retrieved from You Tube: https://www.youtube.com/watch?v=p63mGT1h_Kg&feature=youtu.be&edufilter=NULL

Thales. (2020). *Air Mission Trainer*. Retrieved from Thales Group: https://www.thalesgroup.com/amts

Thanh Nguyen, C. P.-B. (2019). A Review of Situation Awareness Assessment Approaches in Aviation Environments. *IEEE SYSTEMS JOURNAL* .

UK National Audit Office. (2019). *Investigation into Military Flying Training.* UK National Audit Office.

US Department of Defense. (2019). *Report to Congressional Armed Services Committee on initiatives for mitigating military pilot shortfalls.* Office of the Under Secretary of Defense for Personnel and Readiness.