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## **Cleared for take-off: Game-based learning to prepare airline pilots for critical situations**

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# Chapter 1

## Introduction

*On Thursday, January 15, 2009, US Airways Flight 1549 struck a flock of Canada geese, less than four minutes after take-off from La Guardia Airport, New York. With both engines out of order, the Airbus A320 first continued to climb but soon began a gliding descent. The captain took over control from the first officer, who then started working the engine restart checklist. Initially, the captain planned to return to La Guardia, but as he was directed towards a runway by Air Traffic Control, he responded that he was unable to do so. The captain requested landing at a different airport, which was immediately cleared, but again, he was unable to do so. At that time, he announced that he would be landing the aircraft on the Hudson River.*

This aviation incident became known as "the miracle on the Hudson" [156]. Captain Sullenberger prevented a catastrophe that could have killed many, on board of the aircraft as well as in the city of New York, by safely landing the aircraft on the river [124, 187]. If we are ever in the situation to be aboard of such an unfortunate aircraft, we can only hope the pilots are able to perform a similar miracle. Here, we may ask the question, do all pilots have what it takes to perform such a feat?

Pilots of the older generation, like Captain Sullenberger, often have a background with diverse aviation experiences. Sullenberger learned how to fly at age sixteen. He was a fighter pilot in the US Air Force before he became an airline pilot, and he was a glider pilot. At the time of "the miracle on the Hudson", he had over 40 years of aviation experience and almost 20,000 hours of flight time [187]. Many pilots of his generation have had similar careers with military backgrounds, or skills in leisure activities such as gliding or aerobatics before they started working on large, multicrew aircraft. These different experiences helped build their expertise and prepared them for a diverse set of emergencies [120]. Military pilots have been trained for the unexpected. They know how to anticipate and improvise. In leisure activities, such as gliding or aerobatics, pilots are trained to handle the aircraft manually without much automation in various circumstances.

In contrast, younger pilots have often taken a different, more direct route to becoming an airline pilot. They have started their careers in high-tech, modern aircraft with advanced automation, thus putting less emphasis on developing their experience with all kinds of situations and with manual control over the aircraft. Although younger pilots have received extensive training, they have logged fewer hours of flight time when they start their airline careers, and as a result, they have less experience flying in different situations.

Research shows that, in critical situations, pilots fall back on prior experience [163, 185]. If pilots have little prior experience, what do they have to resort to? They may not have the necessary experience to fall back on. An important question is: how can the limited experiences of younger pilots be compensated? This question is currently being investigated in different areas [185].

In general, experience leads to competencies. When pilots fall back on their experience, they rely on their competencies. Thus, competency development may be a way to make up for a lack of experience. We may ask how these competencies can be developed if not by experience. The answer is: competencies may also be developed by training [152].

In our research, we will study the viability of game-based learning as a training method to develop the competencies that are essential in critical situations. For this purpose, we define a suitable training method (see Definition 1.1). Based on this definition we are able to define a viable training method (see Definition 1.2).

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**Definition 1.1 - Suitable training method**

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*A training method is considered suitable if the method has the quality of being appropriate for a particular purpose or situation.*

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**Definition 1.2 - Viable training method**

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*A training method is considered viable if the method is suitable for reaching the learning objective, and is accepted as such by the target group.*

In this chapter, we will start by exploring the lack of experience (Section 1.1). Next, we will discuss two perspectives on game-based learning as a possible way to reduce the experience deficit (Section 1.2). From there, we will formulate the problem statement that will guide our research, along with three research questions (Section 1.3). Then, we will describe the methodology along which we will perform our research (Section 1.4). In Section 1.5, we will provide the structure of this thesis. In Section 1.6, we will state the contributions of our research to the field of game-based learning (GBL). Finally, in Section 1.7, we will describe the environment in which we will perform our research.

## 1.1 Exploring the experience deficit

In difficult situations, experience may be what a pilot needs to bring the situation to a good end. Obviously, young airline pilots have not had the chance to gain the experience that their older colleagues have. Hence, they may lack the diverse experiences that older pilots possess and can rely on.

In this section, we will look at the cause of this difference in experience and the problem it may pose (Subsection 1.1.1). Subsequently, we will look at a possible solution to this problem by providing experience through training (Subsection 1.1.2).

### 1.1.1 The lack of experience

At the start of their airline pilot career, most younger pilots have less experience than their predecessors had when they started their careers. This is a result of at least five factors, viz. (1) a different career development, (2) more automation in modern aircraft, (3) increased overall safety in aviation, (4) new training curricula, and (5) more simulation-based training. Below, we briefly describe these five influencing factors. The order in which we describe the factors is not related to the power of their influence.

- 1. Career development.** For older generation pilots, becoming an airline pilot was usually not an initial career choice. Often they started out flying for the military or flying on air freighters or smaller aircraft. Hence, they already had a substantial number of flight hours before being trained as an airline pilot. Nowadays, youngsters make their choice to become an airline pilot while still in secondary school [120].
- 2. Automation in modern aircraft.** In modern aircraft, many tasks from take-off to landing can be performed by the autopilot. As a result, the pilots can focus on navigating, communicating, and maintaining situational awareness. They monitor the system and only need to take over control manually in case of a deviation. The advanced automation, in combination with highly reliable systems, has many safety benefits. However, as an adverse effect, it leaves the pilots with little exposure to unexpected situations [163]. Furthermore, in unexpected situations, the high-level automation may surprise the pilots by doing something other than they expect [185].
- 3. Increased safety in aviation.** Since the rise of air travel, the safety of air travel has increased immensely. Although the media attention for every aviation incident that occurs, may give an opposite impression, air travel is the safest means of transportation [178]. Paradoxically, this increased safety poses a new threat. As pilots are hardly ever exposed to dangerous situations nowadays, they do not get to experience how it feels and how they should handle themselves under such pressure.
- 4. New training curricula.** Aspiring pilots enrol in flight schools that are often connected to an airline. Since 2006, they can be trained for a specific type of multicrew aircraft to obtain their MPL. With this MPL, they become a first officer on a passenger aircraft while they have only a relatively small number of flight hours. Under the supervision of an experienced captain, they continue training and build their flight hours on that specific type of aircraft. Although the MPL has been implemented in

37 programmes [75], it has not delivered many pilots yet. Furthermore, the Federal Aviation Administration (FAA) of the US Department of Transportation does not recognise the MPL. The MPL will be discussed in more detail in Subsection 2.2.4.

5. **Simulation-based training.** Airline pilot training is an extensive programme with many hours of classroom and computer-based instruction, in addition to practical training. There has been a shift from hands-on flying in a variety of aircraft to training in flight simulators. These simulators are high fidelity copies of actual cockpits, and a simulator flight resembles an actual flight. However, flying a simulator is not the same as flying the actual aircraft. First, the experience is influenced by the pilot's awareness that nothing bad can actually happen [139]. Second, simulation-based training is focused on a relatively small set of scenarios and the pilots more or less know what is coming. Hence, the simulation-based training does not prepare the pilot for a wide range of unexpected situations. And third, in handling the scenarios in the simulator, pilots remain inside the normal flight envelope. The flight envelope refers to the defined limits of conditions such as speed, altitude, and acceleration that the aircraft is permitted to operate within [62]. Flight simulators do not have the aerodynamic modelling for beyond-the-normal-envelope flight [8, 191]. Outside the normal flight envelope, the simulator behaviour is inaccurate.

Together, these five factors have diminished the amount of experience that younger pilots have when starting their airline pilot careers. Experience in itself is only one of the factors that make a pilot a well-qualified, competent pilot. However, through experience, a person will build up competencies. Section 2.4 will provide the necessary background on competencies, competency-based training, and its application in aviation.

Having little experience is not a problem in itself. For most normal situations, the pilots are adequately prepared by their training. The lack of experience may cause problems in the rare event that a serious, non-normal situation surprises or startles the pilot. It may be a situation that the pilot is not familiar with or a situation that is unprecedented. This thesis uses the term *critical situation* (see also Definition 2.5 on p. 21) for such situations as well as for full emergencies.

The technical knowledge and skills of a pilot are the basis of his<sup>1</sup> job performance, but in critical situations, it may come down to his non-technical competencies. For instance, being able to remain calm, and overseeing the situation are crucial to solving the problem at hand. The competencies needed in critical situations will be described in Section 5.1.

### 1.1.2 Providing experience through training

The lack of experience may result in pilots not developing the competencies they need in critical situations. The obvious solution for a problem caused by a lack of experience is ensuring that the pilots gain more experience. However, the current developments in airline pilot training do not support an increase in hands-on experience in the actual aircraft. Alternatively, if the competencies cannot be gained from actual flight experience, they

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<sup>1</sup>For brevity, we use "he" and "his" wherever "he or she" and "his or her" are meant.

need to be gained otherwise. According to Parry [152], competencies can be developed through training. Hence, training may provide an alternative for experience to develop competencies.

Nowadays, an essential part of the current pilot training curriculum is done in flight simulators. Simulator training is suitable for aviator skills and procedures [150]. Additional simulator scenarios can be developed to practice for critical situations with a focus on the essential non-technical competencies rather than the technical skills. However, there are two drawbacks: (1) flight simulators are relatively scarce, limiting their availability and increasing the cost of use, and (2) the use of simulators is a formal way of training as it is highly standardised and regulated. Therefore, we should look for alternative training concepts that can complement simulation-based training in a less expensive, and more flexible way.

In our research, we will focus on GBL, which is a relatively cheap, easily accessible, and motivating training method. We define game-based learning as follows [206].

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**Definition 1.3 - Game-based learning**

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*Game-based learning is a training concept that uses games with specific learning objectives that have been designed to balance gameplay with subject matter, and with the player's ability to apply the subject matter to the real world.*

GBL is also known as *serious gaming*. It is a training concept that may provide a meaningful alternative to actual flight experience or simulation-based training to strengthen the competencies needed in critical situations [111].

Training benefits of GBL have been acknowledged in relation to widely accepted instructional concepts, such as situated learning [24], increased intrinsic motivation [128], and experiential learning [109]. Additionally, GBL brings practical advantages such as making mobile learning [41, 116] and on-demand training [83] possible in a broader context. Other technologies, such as simulations, and augmented and virtual reality, can be incorporated into games to enhance the gameplay and the learning effects. Moreover, learning from games is a good match with the skills, attitudes, and expectations of the new generation of airline pilots [111].

In Chapter 2, we will provide background on GBL and airline pilots. Chapter 3 will elaborate on the design of games for competency development.

## 1.2 Two perspectives on game-based learning

When looking to apply GBL for the development of competencies by airline pilots, two perspectives need to be considered: (1) whether games are a suitable training method to develop competencies, and (2) whether airline pilots will accept to be trained through games.

### 1.2.1 The suitability of games to train competencies

Although most games for learning are being designed and applied for knowledge acquisition [22, 38], other learning outcomes can be achieved. In our research, we aim to investigate the suitability of using games to train competencies. If games are not suitable to train competencies, i.e., if competencies cannot be developed by playing a game, they will not be effective to help airline pilots to handle critical situations.

### 1.2.2 The acceptance of game-based learning by airline pilots

Game-based learning is still a relatively new training concept. Nevertheless, it has been successfully used in the military [20, 135, 158, 182] and health care [46, 77, 205].

So far, in aviation, and specifically in the training of airline pilots, game-based learning has not been applied widely. In part, this is due to legislation. As yet, GBL is not an accredited training method for aviation. Therefore, students cannot log the hours they spent on GBL as training hours. Once legislation allows the hours to be credited, game-based learning may be a viable training method for airline pilots.

To make GBL a successful training tool for airline pilots, (1) the training needs to be accredited, and (2) the intended target group (i.e., the airline pilots) should accept the technology as a training method. If airline pilots do not play the games, they will be unable to reach the learning objectives for which these games were designed.

## 1.3 Problem statement and three research questions

In Section 1.1, we described five factors that contribute to younger airline pilots having little experience at the start of their careers. The lack of experience may cause the pilots not having fully developed all competencies they need in critical situations (see Definition 2.5 on p. 21). Hence, younger pilots may be unable to act adequately in critical situations. In those situations, the outcomes can be catastrophic. Therefore, finding a different way of developing these competencies is crucial.

In Section 1.2, we then briefly introduced game-based learning: an innovative and promising training concept using games for learning. Games may be able to provide younger pilots with an alternative form of experience. This leads to our problem statement, which reads as follows.

**Problem statement:** *To what extent can a serious game be used to train airline pilots to act adequately in critical situations?*

To help answer the problem statement, we formulate three research questions.

Young airline pilots may lack certain competencies that are essential in critical situations. Developing these competencies will be the primary goal of the serious game. The game should be designed specifically for that.

In Section 1.2, we discussed two perspectives on the issue of game-based learning. The first perspective is related to the suitability of a serious game to train competencies. This leads directly to our first research question.



**RQ 1:** *How should a serious game be designed to support competency development effectively?*

The second perspective is related to the acceptance of game-based learning by airline pilots, i.e., whether airline pilots are open to game-based learning and are willing to play a serious game. This raises the question to what extent it matters whether the target group is willing to play a serious game. Playing and gameplay are commonly considered to be voluntary activities [26, 89]. Game designers believe that voluntary gameplay is fundamentally different from mandatory gameplay [69, 133, 135, 160]. Gaming is generally assumed to occur in a voluntary setting: a person has a choice to play or not to play. This will most likely be different in the case of serious games, as they will often be implemented as part of a curriculum. Hence, the gameplay of a serious game will generally be mandatory in nature instead of voluntary. This may have an effect on the outcomes of the serious game. Therefore, our second research question reads as follows.

**RQ 2:** *What is the effect of voluntary play on the outcomes of a serious game?*

A common expectation for a successful training is that the learning leads to a change in behaviour that subsequently can be transferred from the training environment to the work environment. This issue is commonly referred to as "transfer of training". It was first brought up by Woodworth and Thorndike [212] at the beginning of the twentieth century and remains current. However, the first step towards a successful training is determining the reaction of the participants [105]. A positive reaction from the target group is almost a prerequisite. Without it, there may not be any learning, behaviour change or organisational effect. This applies to all types of courses, including courses based on game-based learning.

Consequently, we formulate our third research question as follows.

**RQ 3:** *To what extent do airline pilots accept a game to develop essential competencies for critical situations?*

Together, the answers to the three research questions will allow us to answer the problem statement.

## 1.4 Research methodology

Within our research, we will apply three research methods. To address the research questions, we will use (1) literature research, and (2) experiments. To identify which competencies are essential in critical situations, (3) a job analysis is used. We will discuss the adopted methodology per research question (summarised in Table 1.1).

To answer RQ 1, we will identify and discuss the main requirements that a serious game should meet to support competency development, based on insights obtained from the literature.

To answer RQ 2, we will conduct three experiments to determine the effect of voluntary play on the outcomes of a serious game.

**Table 1.1:** Research methods for answering the research questions

|                     | RQ 1 | RQ 2 | RQ 3 |
|---------------------|------|------|------|
| Literature research | x    | x    | x    |
| Experiment          |      | x    | x    |
| Job analysis        |      |      | x    |

To answer RQ 3, we will perform a qualitative study to determine how airline pilots react to a serious game that is designed as a training method for competencies, which are essential in critical situations. For the qualitative study, we will first design and develop a serious game. This game will be designed in accordance with the main requirements identified in answering RQ 1.

## 1.5 Thesis structure

The structure of this thesis is as follows.

**Chapter 1: Introduction.** In this chapter, the problem statement and three research questions are introduced, along with the research methodology and thesis structure.

**Chapter 2: Background.** In Chapter 2, we will provide background information on the five elements of the problem statement: (1) serious game, (2) train, (3) airline pilots, (4) to act adequately, and (5) critical situations.

**Chapter 3: Towards a design model.** In Chapter 3, we will identify and discuss the three main requirements that a serious game should meet for competency development (in accordance with RQ 1). Moreover, we will present the SG4CD model.

**Chapter 4: The CloudAtlas game: Voluntary play in serious games.** In Chapter 4, we will investigate (1) the effect of voluntary play on the learning effect of a serious game, and (2) the gameplay experience of the players (in accordance with RQ 2).

**Chapter 5: Creating Shuttle to Mars: a game to provide experience.** In Chapter 5, we will start by identifying the competencies that are essential in critical situations. Then, we will report on the design and development of the serious game *Shuttle to Mars*, which is aimed at developing the competencies that airline pilots need in critical situations. The preparations lead to the experiment described in Chapter 6.

**Chapter 6: Measuring the Shuttle to Mars experience.** In Chapter 6, we will investigate how airline pilots react to the *Shuttle to Mars* game and what their attitude is towards training competencies through GBL(in accordance with RQ 3).

**Chapter 7: Conclusions and discussion.** Finally, in Chapter 7, we will summarise the answers to the research questions and provide an answer to the problem statement. Moreover, we will formulate three conclusions and give an outlook on future work.

Table 1.2 gives an overview of the relations between the chapters and the PS and RQs.

**Table 1.2:** Overview of relations between chapters and the PS and RQs

|           | RQ 1 | RQ 2 | RQ 3 | PS |
|-----------|------|------|------|----|
| Chapter 1 | x    | x    | x    | x  |
| Chapter 2 |      |      |      | x  |
| Chapter 3 | x    |      |      |    |
| Chapter 4 |      | x    |      |    |
| Chapter 5 | x    |      | x    |    |
| Chapter 6 |      |      | x    |    |
| Chapter 7 | x    | x    | x    | x  |

## 1.6 Contributions

This research makes the following five contributions to the field of game-based learning.

1. Competency development for airline pilots through game-based learning is explored for the first time. To our knowledge, the *Shuttle to Mars* game is the first game designed to develop the competencies that airline pilots need in critical situations.
2. Our Serious Games for Competency Development (SG4CD) model contributes to a dedicated competency development model for game-based learning. It provides guidelines on what elements need to be present in a serious game designed for competency development.
3. With our *CloudAtlas* experiments, the assumption of voluntariness in serious games is tested for the first time.
4. The reactions of the participants in our experiments show that game-based learning will be well-received by airline pilots.
5. This thesis emphasises that designing effective serious games for experience and highly professionalised users is a great challenge.

Together, the contributions listed above indicate that the competency development of airline pilots may benefit from the introduction of game-based learning into the airline pilot curriculum.

## 1.7 Working environment for the research

The research reported in this thesis was commissioned by the Training, Simulation & Operator Performance department of the Netherlands Aerospace Centre (NLR). NLR is the main organisation in the Netherlands for identifying, developing, and applying advanced technological knowledge in the area of aerospace.

NLR performs research aimed at making air traffic safer, more environmentally friendly, and more efficient. The Education & Training team of the Training, Simulation & Operator Performance department focuses on innovations in the training of aerospace personnel, such as pilots, air traffic controllers, and astronauts.