

Review

# A Review of Training Procedures for Simulated Engine Failure after Take-Off Exercises with Twin-Engine Aircraft under 5700 kg

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**Abstract:** Engine failure after take-off (or one engine being inoperative) is an exercise conducted as part of multi-engine flight training and on-going competency checking. To prepare pilots to manage a real in-flight emergency, this exercise has traditionally been conducted immediately after take-off. This has led to increased risks of fatal accidents due to the reduced height at which these exercises are typically conducted. Yet, there is variation in the heights stipulated in training procedures published by different stakeholders worldwide. Additionally, the conduct of the exercise has resulted in fatal accidents worldwide. This paper aims to review the previous literature on aviation training and aviation occurrence data to determine what empirical data exists to support the method of conducting simulated engine failures. Peer-reviewed academic publications on aviation training, aviation occurrence databases such as aviation investigation reports, and guidance materials published by aviation authorities on simulated training exercises will be included in this paper. It was found that the previous research on these exercises has focused on the transfer of motion cues or pilot responses to abnormal situations, but did not include specific data comparing pilot performance at different heights above ground level. A review of aviation occurrences found that actual engine failures occurred at higher heights than those used in simulated engine failures. A comparison of the guidance published by aviation authorities identified variations in the minimum altitude published and differing justifications for the minimum height chosen. Future research is needed to compare pilot performance during simulated engine failures to determine the ideal height to conduct the exercise to be representative of an actual engine failure while maintaining safety margins.

**Keywords:** aviation; simulated training; engine failure; human factors



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## 1. Introduction

Engine failure after take-off (or one engine inoperative) is a compulsory exercise conducted as part of multi-engine flight training as documented by the Australian aviation safety regulator, the Civil Aviation Safety Authority [1]. Similar requirements for this training apply internationally. This exercise involves an instructor simulating an engine failure on one engine and the student (or trainee) is required to identify the engine that has failed and manage the situation to keep the aircraft in controlled flight. These exercises have been conducted at a low height (below 400 ft above ground level (AGL) is the height measured in feet above the ground. The other method of measurement is above mean sea level (AMSL), which is the height in reference to the average sea level datum), or 122 m) to represent an engine failure after take-off. However, lower heights present increased risks as the trainee and instructor have less time available to manage the situation effectively. These include a smaller margin for recovery, lower speed, and increased drag due to aircraft configuration. In multi-engine aircraft, this exercise can be conducted in a simulator. However, the manoeuvre is also conducted in real aircraft as part of the training program published by national aviation authorities. There is an increased risk with aircraft

under 5700 kg as simulators for these aircraft may not be widely available and the exercise is conducted with real aircraft.

There have been several fatal accidents in Australia [2,3] and overseas [4] during the conduct of simulated engine failure after take-off exercises. In Australia, two-thirds of the accidents that were conducted at or below 400 ft, where the height was known, resulted in a fatality. A review of the Australian Transport Safety Bureau's occurrence data found that actual engine failures on twin-engine aircraft occurred on average at 1500 ft (457 m) above mean sea level [3]. This raises the question of whether the training that pilots are doing to handle an engine failure in a multi-engine aircraft may not be reflective of the real-world evidence.

The literature review presented in this paper explores previous studies in aviation training, focusing on applied research on training for specific manoeuvres or scenarios. The review includes industry publications on training, regulations relating to engine failure training, and investigation reports and aviation occurrence data.

## 2. Methodology

The systematic review used a comprehensive methodology to include all relevant papers to understand the available research on aviation training, with a specific focus on studies using simulators. There were three types of papers reviewed: (1) peer-reviewed journal articles, (2) aviation investigation reports, and (3) regulatory documents on aviation training, including advisory publications and legislation.

As part of this review, research papers were searched using key words 'aviation' OR 'aircraft' AND 'training' AND simulator AND human factors OR human performance, as well as specific human performance topics including 'workload' OR 'attention'. These terms were searched in the fields of the title, abstract, and keywords of the papers. Only papers published in English were reviewed. The databases searched included Google Scholar, Scopus, and Science Direct. These databases provide a range of sources to assist with identifying studies across multiple interdisciplinary areas.

The research question guiding the literature review was 'Have there been any previous studies reviewing the heights used in simulated engine failures?'

The results of the literature search were filtered by reviewing the papers' titles, key words, and abstracts, which resulted in 54 articles selected for the review. The inclusion criteria for the review were:

- The paper must involve participants flying an aircraft (an airplane or helicopter);
- The paper must involve a simulator or a simulated scenario;
- The paper must be related to training to improve and/or measure performance in operational or human factor domains;
- The paper must be empirical or experimental research.

The research reviewed comprised of participants across a wide range of ages, genders, and flying experiences.

The second part of the review involved searching through aviation investigation reports published by investigation agencies. These agencies' websites (in English) were searched for reports involving simulated engine failure exercises. The search terms used were 'simulate engine failure' or 'training AND engine failure'. The reports were then reviewed to include only twin-engine (piston or turbo-propeller) airplanes under 5700 kg and that the phase of flight at which the accident occurred was ascending (at take-off or in the climb phase). The search resulted in 12 investigation reports from agencies in Australia, the United States of America, and Canada.

The third part of the review involved searching for aviation regulatory authorities' training publications. Regulatory authorities' websites (in English) were searched for their published documents using the terms 'simulated engine failure' in twin-engine airplanes. The search yielded publications from Australia, the United States, Canada, the United Kingdom, and the European Union. These authorities were contacted by email using the publicly available email addresses from their website.

### 3. Literature Review

#### 3.1. Simulator Training Research in Aviation

Since the development of aircraft, simulators have also been used as a training method [5]. The first flight simulators were a ground-based replica of an aircraft for pilots to practice using the controls. Advancements in computing technology have been applied to simulators as they can have dynamic displays and even motion. Given the lower relative cost of simulators compared to actual aircraft, it has become a cost-effective method to train pilots. Research has shown that training in the simulator reduces time learning in the aircraft [6,7]. However, another review has found that the effects of simulator training did not improve performance after an average of 5 h [8].

Many studies have repeatedly demonstrated benefits of simulator training to improve flying skills [9–11]. Simulator training has many benefits including training large numbers of pilots and also providing the opportunity to practice manoeuvres that are hazardous in an actual aircraft. Simulators are also recognized as a valid training technique to meet training requirements set by regulations. Further, they have also been used for training in other industries, such as medicine and shipping.

The research in aviation training using simulators ranges in focus from training in normal operations to responses to abnormal situations. Flight simulators are a common method used in aviation training as these enable exposing trainee pilots to conditions similar to real scenarios. They can also be high fidelity, meaning they are very similar to the actual aircraft, with the ability to control and program for scenarios as required. In some instances, the addition of motion cues to a simulator has improved participants' subsequent performance [12]. It has been found that providing participants with simulator training enhances their subsequent performance in that particular skill or scenario, indicating that training transfer has occurred [13]. In the context of training for normal operations, previous research has demonstrated that simulator training has improved pilot performance with basic flight control skills [14–21], adherence to visual flight rule procedures (such as maintaining separation and coordination with other aircraft in the circuit) [22,23], instrument flying skills [23–28], landing [29–32], low-visibility procedures [33], and risk assessment skills during low level flight [34]. Improved performance in these studies were measured by there being less variation in flight path tracking, flying instructor assessments, the mean higher altitude, and fewer landing attempts.

As well as normal situations, research has demonstrated that previous experience in a simulator improves performance in response to abnormal situations in a simulator [35]. It has been found that pilots who practiced unusual attitude recovery in a simulator performed better when retested in a simulator when presented that scenario than pilots who practiced unrelated procedures [36]. This was measured by higher instructor ratings and faster task completion times.

A study on the transfer of decision-making [37] found that pilots who had practiced an abnormal scenario applied decision-making principles (situation assessment and action selection) and made fewer errors than pilots who had not previously been exposed to that scenario. Specifically, the pilots who had not previously practiced the abnormal scenario also made more errors during the action selection phase. This implied that previous experience in the decision-making phases while managing an abnormal situation transfers when again presented with the same scenario.

Other research [38] has found that when using scenario-based training with exposure to simulated emergencies involving a parachute deployment, participants using this method obtained higher observer ratings than those who only reviewed the procedure. Further, the participants who completed this training were more likely to deploy the parachute at the correct time and altitude.

As well as aircraft handling skills, judgement and decision-making can be transferred after simulator training. Connolly [39] has found that participants who received classroom training and instructional simulations where they experienced several in-flight events performed significantly better than a control group when later assessed on their ability

to handle these events by instructors and demonstrated a significant amount of change compared to their first attempt. Similarly, other researchers have found that pilots in a simulated flying condition positively transferred risk-averse behaviours (flying at a higher altitude) when flying in an actual airplane when they were actively involved in the flight [40]. Further, providing feedback was only beneficial if pilots could recall similarities between the test flight and other flights.

It was found that student pilots [41] who received simulator-based training performed better than those who did not have training in upset recovery through the application of control of G forces, correcting throttle and upset recovery response. It was also found that stress adversely affected performance. This related to the pilot's using smaller control inputs under stress to correct the upset as they became unaware of how much input they were using.

Elaborating on the previous research discussed in the paragraph above, it was found that student pilots who received simulator-based training could return the aircraft to straight and level flight quicker following an in-flight upset compared to those who did not receive additional training [42,43]. Notably, the amount of altitude loss was not significantly different between groups. A follow-up study measuring the transfer of simulator training to a real aircraft was conducted with these groups, and it was found that the pilots who received simulator-based training lost less altitude than those who did not have this training and were also able to return to straight-and-level flight quicker than those who did not receive this training. Replicating this experiment with a motion simulator [44] found that both groups that had simulator training lost less altitude than the group who did not complete this training. There was little difference in performance between the two simulator groups (high- and low-fidelity simulators), indicating that training in simulators of different fidelities can improve performance.

Similar research used a simulator to train for upset recovery from unusual attitudes, spins, and stalls using visual references [45]. It was found that pilots who completed the simulator training improved their performance more than the control group. They were able to manage the aircraft recoveries in less time, instructor ratings of performance were higher and participants experienced a decrease in reported time pressure. Although the simulator did not have motion cues, a transfer of skills to a real aircraft was demonstrated. In research where motion cues in a simulator were used to train visual flight rules pilots in spatial disorientation conditions, it was found that pilots in the motion condition had a quicker spin recovery time compared to pilots who did not have motion cues or any training [46].

As well as flying skills, research in aviation training has found that the ability to manage the stress associated with an abnormal situation can be transferred. Research found that participants who flew in a simulator with an introduced stressor and were given associated strategies to manage stress performed better when flying a real aircraft than participants who were not exposed to a stressor [47,48]. Performance was measured by pitch, roll, and lateral and longitudinal acceleration variation as well as instructor ratings.

### *3.2. Previous Engine Failure after Take-Off in Twin-Engine Airplanes Research*

There has been research on simulated engine failure after take-off in a simulator and real aircraft. Take-off is considered one of the highest workload phases of flight based on subjective and physiological data [49,50]. The highest recording of stress was also in this phase [49,50].

Previous engine failure after take-off research evaluated the use of motion cues and whether motion training can be transferred and improve performance. Researchers examined the use of the vertical motion transfer of cues using a simulator [51]. Pilots were required to respond to an engine failure after take-off. It was found that the pilots who had motion cues believed that it helped them with the exercise. However, there were no significant differences between groups who had motion cues and those who did not when managing heading deviation. Conversely, there was a significant difference between

groups concerning rudder pedal input reaction time, where the group who did not train with motion had a faster reaction time than other groups who had different levels of motion. One reason proposed by the authors is that the no-motion group may have had to rely on visual cues. As the purpose of the research was to evaluate the use of motion in simulations rather than the exercise itself, this study included limited information on the exercise's method and did not include the aircraft's height. The only information included about the engine failure was when it would occur, which was when the landing gear was extended.

In another study about engine failures, researchers examined the use of a motion simulator and a fixed-based simulator and whether there were any differences in performance in an engine failure after a take-off exercise [52–54]. It was found that there were no differences between groups. As the purpose of the research was to evaluate the use of motion in simulations rather than the exercise itself, this study included limited information on the method the exercise was conducted in and did not include the aircraft's height when the engine failed. This research was elaborated further to assess whether pilots who undergo initial training would benefit from learning motion cues [55,56]. Still, there was no significant difference in the response times of pilots who did not receive motion cues during the transfer phase. While this research included detail for some of the heights at which the engine failed, there was no comparison between performance as the purpose of the study was to evaluate the effect of motion in training.

A similar study conducted a quasi-transfer simulator training study where pilots were involved in an engine failure after take-off training exercise with motion and without motion to examine whether training with motion cues enhances performance [57]. The results showed there were few differences in control inputs across motion conditions while managing the failure. Similar to the research conducted and described above, there was no information recorded about the height at which the engine failure occurred.

Another study on motion cue transfer used engine failure after take-off as an example scenario to examine whether these cues affected the pilot's ability to detect the failed engine and recover the aircraft [58]. It was found that motion cues significantly affected heading deviation where pilots who had these cues deviated less from their desired heading compared to the other conditions. As the main focus of the study was to evaluate the transfer to motion cues, there is no information on the exact altitude at which the engine failure occurred except that it would occur at a random altitude after a rotation below 100 ft.

There was a study on available cues of an engine failure in twin-engine propeller aircraft focused on the available cues [59]. Specifically, the research involved on group of pilots who relied on traditional methods to identify an engine failure (aircraft yaw) and another group who had cockpit lights indicating a failure. As the purpose of the study was about optimal cues to identify the failed engine, there was limited information on the height at which the engine failure occurred except how many seconds after lift-off the failure occurred. Further, there was no comparison of pilot performance between the different times the failure was programmed.

Other researchers have conducted studies measuring workload during simulator and actual aircraft sessions, which included managing an engine failure in a twin-engine aircraft [60]. Workload was measured by rating scales and heart rate. The results showed that pilots had an increased heart rate in the simulator compared to the aircraft for this failure and had a high subjective rating for mental workload. A reason for the increase of workload in the simulator compared to the aircraft proposed in the study was that the pilots were aware of when the engine failure would occur in the simulator and may have anticipated a high workload situation. In contrast, in the aircraft, it occurred at a less predictable time. This is because their heart rate increased in anticipation of the event in the simulator, and in the aircraft, they had a lower initial heart rate but more rapid increase. The research did not specify the height at which the engine failure occurred, except that it happened around 13 min into the session, which was likely in the climb or cruise phase. The failure also occurred at different times in the session; in the simulator, it occurred after take-off and in the aircraft during cruise flight at a safe altitude.

Researchers conducted research on a pilot's stress responses to an abnormal situation, using engine failure after take-off as an example [61]. Stress was defined by the authors in this study as the negative appraisal of a situation. The results found that the participants' visual search rate predicted the instructor's evaluation and heading deviation. As the purpose of the research was to evaluate pilots' stress responses, there is no information on the specific height at which the engine failure occurred.

Other research conducted to evaluate heart rate variability during emergency situations included engine and alternator failures [62]. One of the engine failures was during take-off. It was found that the pilots' heart rate increased the most when the engine failure occurred during take-off compared to the other situations. Although the research included different heights for the engine failure, the specific heights were not specified as the purpose was to compare heart rates across conditions.

As well as stress, research has been conducted into managing surprise, or responses to unexpected events. Casner et al. [63] conducted research on pilot training in abnormal situations where pilots were exposed to variations in cues. One of the abnormal situations was an engine failure after take-off and the measures were whether they continued the take-off and their lateral control of the aircraft. It was found that of the 18 pilots, 2 aborted the take-off after the critical take-off speed. Based on the information in the study, it was ascertained that the engine failure occurred during a take-off roll, as the study referenced critical speeds. As the purpose of the study was to evaluate the pilot response to an unexpected abnormal situation, limited information was provided about when the engine failure occurred.

Similarly, research found that pilots who practised engine and rudder failures in an unexpected or variable manner required less time to manage a related failure during a surprise test compared to pilots who practiced these failures in a predictable manner [64]. In this study, the timings (or blocks) the engine failure occurred at were gear lever up, speed 65 kt, rotate, altitude 270 ft, gear halfway up, and altitude 310 ft. The pilots in the unexpected/variable group were only advised that there would be a malfunction, but not specifically during which block, whereas the control group were advised before each block that a failure would occur. Further, a surprise test occurred at 55 kt, with the height not specified. This study did not include a performance comparison for each block of engine failure, for instance, between the different heights and speeds for each block.

As part of the Australian Transport Safety Bureau's investigation into a collision with terrain near Renmark, South Australia, involving a Cessna Conquest, the Australian Transport Safety Bureau occurrence data between 2008 and 2017 of checking or training accidents and actual engine failures or malfunctions were reviewed [3]. Of the 24 occurrences for a twin-engine, VH-registered aircraft under 5700 kg conducting training or check flights, there were three accidents, one of which resulted in fatalities during simulated engine failure after take-off. Outside of this period, a fatal accident during a simulated training exercise occurred in 2019. It was found that the fatal simulated training accidents occurred at or below 400 ft, where height was known.

In the same period, 405 actual engine failures or malfunctions were reported. Forty-three percent were in the take-off/climb phases of flight (up to 7600 ft). Nine of the 405 accidents resulted in fatalities (2%), but 7 of the 9 [engine failures or malfunctions] accidents were in the take-off/climb phases of flight. The two fatal accidents occurred at or above 1500 ft AGL.

A review of the data shows that accidents occurring after an engine failure are rare. However, when accidents occur, they are likely to be during the take-off/climb phases of flight. Additionally, the fatal accidents during actual engine failures occurred at higher altitudes compared to those occurring during training.

Furthermore, the report noted [3] (pp. 62–63)

At present there is insufficient information available to accurately assess the accident rate associated with simulated engine failures, compared to the accident rate of actual engine failures occurring after take-off. Specifically, there is no data collected about the number of time asymmetric exercises are conducted in aircraft

in Australia, in either flight training or company-based training and checking, which means the exposure is unknown.

Without knowing the exposure rate and how the training exercises are being conducted, including whether they accurately represent the conditions of a real engine failure, the ATSB could not determine whether the benefits of conducting simulated engine failures at a low level outweighed the risks. Further research in this area is required to answer that question.

### 3.3. Simulated Engine Failure after Take-Off

In Australia, pilots are required to meet competencies outlined in Part 61 of the Manual of Standards. To obtain the multi-engine aeroplane class rating, the pilot completes the aeroplane advanced manoeuvres unit of competency, which includes performing stall recovery in simulated partial and complete engine failure conditions.

In Australia, the Civil Aviation Safety Authority's Civil Aviation Advisory Publication 5.23-1(2) Multi-engine aeroplane operations and training identified conducting flight operations at a low level as a risk. The publication acknowledged that [1] (p. 19)

Any flight operation at low altitude has potential dangers. Trainers have debated over the decades on the value of practicing engine failures after an actual take-off near the ground. The consensus is that despite the risks, pilots must be trained to manage these situations in multi-engine aircraft.

The publication also stipulated that instructors should consider not simulating engine failures below 400 ft above ground level to provide a safety margin. A strategy discussed to manage the risk was a thorough briefing after planning the exercise to reduce the level of in-flight analysis required, especially if a critical decision has to be made following an engine failure after take-off. The aim is to reduce the workload that may distract from the critical task of flying the aircraft.

Before simulating engine failures in multi-engine aircraft, instructors must be aware of the implications and be sure of their actions. The publication states that the instructor should consult the aircraft flight manual or pilot operating handbook for the manufacturer's recommended method of simulating an engine failure. If there is no recommended method, then the publication guidance can be used. Before undertaking the task, the instructor must ensure that the aircraft is not in a dangerous situation to start with, such as the aircraft flying too slow, too low, in an unsuitable configuration, or hazardous weather (wind, ice, or visibility) being present. The publication also emphasizes that there is no benefit to introducing more risks than the emergency being trained for. Though there is guidance available for the conduct of the exercise, it is still the instructor's discretion on when the engine failure is simulated.

The publication recommends that simulating an engine failure at a low level is done by closing the throttle for piston aircraft. After the engine has failed, the pilot must identify which engine is not producing power and maintain control at an optimal speed. Procedures include

- Controlling the aeroplane. Prevent yaw with the rudder and adjust the nose attitude to a position where the aircraft can maintain or accelerate to the best single-engine rate-of-climb speed ( $V_{YSE}$ ). The wing may also be required to be lowered towards the serviceable engine.
- The pilot must ensure that full power is applied to the good engine and the gear and flap are selected up—'Pitch up, mixture up, throttle(s) up, gear up, flap up'.
- The pilot must identify the failed engine (dead leg, dead engine method) but maintain control of the aircraft during this process.
- Once the failed engine is confirmed, the pilot must close the throttle of the failed engine and confirm that the engine noise does not change or that no yaw occurs towards the live engine. They also need to visually identify the failed engine propeller lever before activation.

To manage an engine failure situation, the pilot must maintain control of the aircraft at an optimal speed. The pilot must stay above  $V_{MCA}$ , which is the minimum control

speed of an aircraft, to maintain directional control with one engine inoperative and adjust the aircraft attitude to achieve the best single-engine angle of climb speed ( $V_{XSE}$ ) or best single-engine rate of climb speed ( $V_{YSE}$ ) so that optimum climb performance is attained for the flight situation.

Several countries publish minimum heights at which the exercise can be conducted in their respective documents. Based on the guidance documents, the most common height appears to be 400 ft. A summary is found in Table 1.

**Table 1.** Summary of the minimum heights above ground level recommended for simulated engine failures in twin-engine aircraft.

Country	Height
Australia (Civil Aviation Safety Authority)	400 ft
Canada (Transport Canada)	500 ft
United States (Federal Aviation Administration)	400 ft
United Kingdom (Civil Aviation Authority)	300 ft
European Union (European Aviation Safety Agency)	400 ft

The United States Federal Aviation Administration's Commercial Pilot—Airplane Airman Certification Standards [65] (p. 18) stated that

On multiengine practical tests, where the failure of the most critical engine after lift off is required, the evaluator must consider the local atmospheric conditions, terrain, and type of aircraft used. The evaluator must not simulate the failure of an engine until attaining at least  $V_{SSE}$  (minimum safe single-engine speed)/ $V_{XSE}$  (best single-engine angle of climb speed)/ $V_{YSE}$  (best single-engine rate-of-climb speed) and an altitude not lower than 400 feet AGL'.

The Federal Aviation Administration publication, Flying twins safely [66] (p. 8) provided additional guidance and noted that

Low-altitude engine failure is never worth the risks involved. Multiengine instructors should approach simulated engine failures below 400 feet AGL with extreme caution, and failures below 200 feet AGL should be reserved for simulators and training devices.

The Federal Aviation Administration Airplane flying handbook [67] (p. 36) noted that

When training in an airplane, initiation of a simulated engine inoperative emergency at a low altitude occurs typically at a minimum of 400 feet AGL to mitigate the risk involved and only after the learner has successfully mastered engine inoperative procedures at higher altitudes. Initiating a simulated low-altitude engine inoperative emergency in the airplane at an extremely low altitude, immediately after liftoff, or below  $V_{SSE}$  creates a situation where there are non-existent safety margins.

Transport Canada's [68] (p. 37) Instructor guide and multi-engine class rating stated that 'it is not recommended to simulate engine failures below 500 ft AGL'.

The United Kingdom Civil Aviation Authority's [69] (p. 3) Guidance to training captains and trainees, simulation of engine failure in aeroplanes states 'that for multi-engined single-pilot aeroplanes it is recommended that engine failure shall not be simulated until reaching a minimum height of 300 ft above ground level'. This guidance also includes that an in-flight shutdown can only be conducted above 5000 ft.

The European Union Aviation Safety Agency's [70] (p. 1102) Easy Access Rules for Air Operations (Regulation (EU) No 965/2012), under one engine inoperative stated that 'the steady gradient of climb at an altitude of 400 ft above the take-off surface' should be demonstrated. These published heights are of importance as this is where many of the accidents have occurred.



In response to a question about their documents, the Federal Aviation Administration reported that 400 ft was deemed adequate to mitigate the risks and increase safety during multi-engine training and testing upon reviewing previous engine failure after take-off accidents. This height was also used, as it was referenced in the aircraft certification requirements Title 14 of the Code of Federal Regulations (14CFR) Part 23 at the time.

The Civil Aviation Safety Authority of Australia reported that 400 ft was used in their guidance, as it was used in previous editions of the document. The regulator advised that there are no plans to update the guidance.

When asked about the reasons for the 400 ft minimum height choice, the European Union Aviation Safety Agency referred to the Certification specification for Normal, Utility, Aerobatic and Commuter Aeroplanes which includes performance requirements with one engine inoperative. Specifically, one engine inoperative is to be demonstrated by a positive steady gradient of climb at an altitude of 400 ft.

A review of guidance materials from New Zealand, Hong Kong, and Singapore found that no minimum height was stipulated for conducting simulated engine failure after take-off exercises. Representatives from these countries' civil aviation authorities indicated in their response that it was at the instructor's discretion to select a height suitable for the student to practice this manoeuvre, as they are the subject matter experts. It should be noted that this is a small sample of regulators and it is unknown what other countries' publications state (due to difficulties in searching for training documents, only materials in English are referenced).

#### 3.4. Simulated Engine Failure after Take-Off Accident Investigations

Accident investigation reports involving simulated engine failure exercises with twin-engine airplanes under 5700 kg from Australia, the United States, and Canada from the past 20 years were reviewed. Half of the accidents listed in Table 2 below show that the simulated engine failure was conducted at or below 400 ft.

**Table 2.** Summary of engine failure after take-off accidents.

Height	Number of Accidents	Number of Fatalities
0–100 ft	2	2
100–200 ft	2	4
200–300 ft	2	2
300–400 ft	2	3
Above 400 ft	4	2

Based on the investigation reports, if an accident occurred when the engine failure was simulated at a lower height, it was more likely to be fatal. All the accidents where the height of the exercise was below 400 ft had fatal injuries.

#### 3.5. Summary

Current research into the conduct of simulated engine failure after take-off in twin-engine aeroplanes under 5700 kg is limited. The only previous research that has used this exercise focused on the transferability of motion cues or as an example of an abnormal situation to measure the pilot's response. These research examples have limited or no information about the specific heights used in the exercises, most likely because it was not the focus of the studies.

There is variability in the published minimum height that the exercise is to be conducted at across different countries to ensure their accepted safety margins. Additionally, some countries do not specify a safe minimum height at all. Of the countries that publish a minimum height, there does not seem to be a clear reason why it was chosen. Most likely, this is because of historical regulations, aircraft performance characteristics, and the discretion of the subject matter experts, such as flying instructors. A review of the accident data indicated that actual engine failures occur higher than the training exercises [3].

No previous research specifically examines the heights used in simulated engine failure exercises, and therefore, it is not possible to evaluate whether the safety benefits outweigh the risks of conducting these exercises, as mentioned in the Australian Transport Safety Bureau investigation report [3].

#### 4. Discussion and Conclusions

There is no previous research specifically evaluating the performance of pilots during simulated engine failures at different heights. Previous research has focused on motion cues or the exercise was used to measure pilot responses to an abnormal event. Future research should focus specifically on the heights that simulated engine failures are conducted at to compare pilot performance across these conditions. Potential heights that could be used in the study should be based on the issues discussed in this paper. Examples include the heights from previous investigation reports and published information from regulatory authorities and aircraft manuals. Variables to measure could include flight parameters such as airspeed, pitch, and time, as well as eye-tracking to ascertain the instruments that students focus on during engine failures. Subjective measures, including workload ratings and instructor scores can also be used to evaluate an individual's experience and performance, respectively.

There is no empirical data to support the minimum height stipulated in regulatory guidance documents on conducting simulated engine failure exercises. There is also variation across countries, with different explanations for the decision to publish a particular height in their documents. It is important to evaluate the heights used in this exercise because of the risks involved and whether these are representative of actual engine failure scenarios.

As well as adding to the existing literature about how engine failure training is conducted, this research has safety implications. A review of previous occurrence data worldwide has shown that this training exercise has contributed to multiple serious and fatal injuries. Results from future research could be used to influence aviation training guidance and processes and the skill development of pilots. Further, the research benefits the aviation industry also from an economic perspective, as it has potential to reduce the risk of fatalities and the loss of aircraft, both of which have significant cost implications. As engine failure after take-off is a high workload task, improving these practices has the potential to decrease airspace complexity, which subsequently benefits all users of the shared airspace.

From an industry perspective, this review can assist regulators and policy makers when reviewing their guidance materials on the conduct of simulated engine failure training exercises. A greater knowledge of existing procedures and their success reduces further regulatory burdens, and reduces the need for agencies to conduct their own research or rely on historical evidence. Similarly, further research in this area provides additional data to manufacturers of twin-engine airplanes on its performance characteristics.

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