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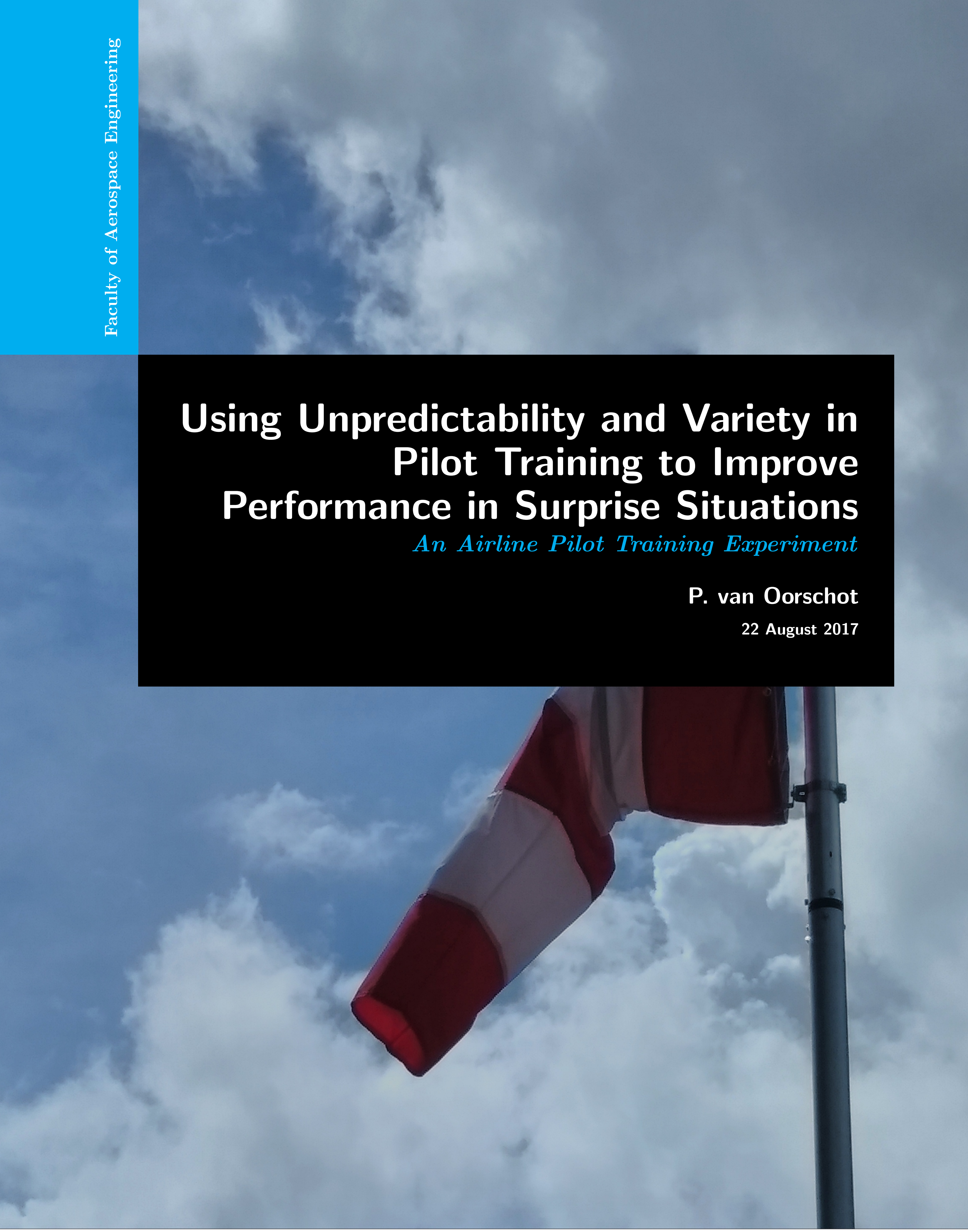

Using Unpredictability and Variety in Pilot Training to Improve Performance in Surprise Situations

An Airline Pilot Training Experiment

P. van Oorschot

22 August 2017

Delft University of Technology

Challenge the future

Using Unpredictability and Variety in Pilot Training to Improve Performance in Surprise Situations

An Airline Pilot Training Experiment

Master of Science Thesis

For obtaining the degree of Master of Science in Aerospace Engineering
at Delft University of Technology

P. van Oorschot

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Control and Simulation

The undersigned hereby certify that they have read and recommend to the Faculty of Aerospace Engineering for acceptance a thesis entitled **"Using Unpredictability and Variety in Pilot Training to Improve Performance in Surprise Situations"** by **P. van Oorschot** in partial fulfillment of the requirements for the degree of **Master of Science**.

Dated: 22 August 2017

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Preface

One of the reasons I chose the Control & Simulation department was my interest in the human aspect in the cockpit. For my thesis I was therefore looking for a topic involving humans, with their strengths and weaknesses, in the cockpit. This brought me to René, who told me about an assignment to look into the effect of training variability in training for engine failures in take-off, using a Piper Seneca model and SIMONA. After one night of sleep I decided that this was the topic for my thesis. That was almost eleven months ago.

Starting this report I would like to spend some words to name a few of the people that made this possible. First of all my daily supervisors. René, thanks for providing me with this interesting thesis topic, the valuable insights in setting up the experiment and the assistance with DUECA. Annemarie, thanks for all the help with the experiment, the feedback you provided and the ideas for the direction of this research. I wish you the best for the remaining years of your PhD and hope this work contributed.

I would like to express my gratitude to Olaf for entrusting me to operate the SIMONA. Thank you for the time you spend getting the simulation to work on SIMONA and all your assistance in performing the experiment. I'm sure the countless times you ran up the stair gave you some good exercise. Herman, thanks for helping me start with the Seneca model, your ideas for scenarios and helping with testing on the SIMONA. The work you put in the model was put to good use, and hopefully one day someone else will use the Seneca model for their research. Dirk, thanks for letting me borrow your DUECA sound playback and FlightGear weather modules and showing me how to include FlightGear on my own machine. The sound helped a lot in emerging the pilots in the simulation, while the weather module made sure that the wind sock gave correct information on the wind in the simulation. Having outside visuals available during development was of great help for testing and tweaking all scenarios.

Many thanks to my parents for supporting me during my studies. I'm grateful you made these years in Delft possible. Last but definitely not least, Taylor. Thanks for the support and all the fun plans of what to do after graduation.

Peter van Oorschot

Delft, 11 Augustus 2017

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Acronyms

ARI	Aileron-Rudder Interconnect
CPL	Commercial Pilot License
DUECA	Delft University Environment for Communication and Activation
EBT	Evidence-based training
ECI	Experiment Control Interface
FSTD	Flight Simulation Training Devices
GUI	Graphical User Interface
INCO	Initial Conditions
ISA	International Standard Atmosphere
LOC-I	Loss of Control In-Flight
MBT	Manoeuvre-based training
MCP	Mode Control Panel
MTOW	Maximum Takeoff Weight
PAPIs	Precision Approach Path Indicators
PFD	Primary Flight Display
SBT	Scenario-based training
UPRT	Upset Prevention and Recovery Training

Thesis outline

This report is divided in three parts:

I Journal paper: Paper summarizing the study performed and providing the results of the experiment.

II Preliminary report: Report containing the background of this study, including literature and details on the set-up of the performed experiment.

III Appendices: Addition documents related to the experiment and the software developed for performing the experiment.

Part I

Paper

Using Unpredictability and Variety in Pilot Training to Improve Performance in Surprise Situations

Peter van Oorschot, Supervisors: Annemarie Landman, M. M. (René) van Paassen, *Member, IEEE,* and Max Mulder

***Abstract*—Loss of Control In-Flight is the most prevalent cause of fatal accidents in commercial aviation. Surprise and startle are commonly suspected as contributing factors. Aviation authorities recommend to include surprise in training. However, studies indicate current training is in some cases too predictable as variations are brought to a minimum, with a focus on predetermined responses.**

This study aims to test if using unpredictability and variety in training better prepares pilots for surprise situations. Toward this end, a flight simulator experiment was designed in which 21 airline pilots, divided over two groups, participated. Each group was provided with a short training containing half an hour of flight time. One group was given a predictable training without variety while the other group was given an unpredictable training with variety. Results show that with minimal impact on the training, performance is better in a surprise scenario related to the training. In a surprise scenario unrelated to the training, no effect was found.

The results suggest that using unpredictability and variety in pilot training improves performance in surprise situations, underlining the need to make pilot training less predictable.

***Index Terms*—training, pilots, unpredictability, variety, surprise, malfunction, abnormal events**

I. Introduction

TODAY pilots have assistance from automation and advanced tools for control, navigation and communication. At the same time the aircraft and these systems have become more reliable. This has led to a decrease in the number of accidents and fatalities. However, the increased level of automation moved the pilot's task from manually flying the aircraft to monitoring of the cockpit, resulted in limited flying practice during operations. Loss of Control In-Flight (LOC-I) is the most prevalent cause of fatal accidents in commercial aviation [1]–[4].

A recent study indicated that recurrent pilot training is primarily focused on dealing with specific anticipated problems [5]. The training is in some cases too predictable as variations are brought to a minimum, with a focus on predetermined responses to events that, in the context of the training, hardly come as a surprise. Unexpected events and how to deal with them is not always explicitly addressed. Surprise and startle are commonly suspected as factors contributing to the inappropriate actions made by the flight crew in LOC-I accidents [6]–[8], see for example Colgan Air flight 3407 [9]. Surprise can be conceptualized as a mismatch between what is observed and the pilot's "frame" of understanding of the situation. This requires a change in understanding of the situation, termed "re-framing" [6], [10]. Re-framing is thought to be very difficult under stress [11], which explains the difficulty of responding to out-of-frame situations. For this reason, aviation authorities indicate that surprise should be included in upcoming simulator based LOC-I prevention training [7], [8], [12].

Time available for recurrent training is limited and the contents of training programs is carefully regulated and under pressure. Therefore the time spent on training has to be used optimally. This means the time available for training is often spent on specific skills that must be tested according to regulations. This results in pilots showing the appropriate actions in the test. However, studies show that pilots have difficulty applying the learned procedures when events come unexpected [13]. Therefore, the response as tested after the training can differ greatly from the response which can be expected in a surprise situation.

Current pilot simulator training and testing, as mandated by the authorities, is thus not always optimal in preparing pilots for the range of situations that can occur in normal operations. We expect that adding unpredictability in training can be a possible solution to better prepare pilots for surprise situations.

The goal of this study was to test recommendations to reduce the predictability in airline pilot training, leading to a better training of flight skills in a way that is transferable to scenarios different from those explicitly trained. This should lead to better use of time and resources to best prepare the pilot, not just for the test pilots have to perform, but the situations they can face in the day-to-day operations. Also important in the training is to give the pilot the confidence that they can handle the situation, especially when initially they have no idea what is going on and do not feel in control. Care should be used to avoid a negative learning experience in surprise training [7].

To find if there indeed is a benefit in training with unpredictability, we designed an experiment wherein we compare two trainings which differ in their predictability. Each training is given to a group of airline pilots. By providing unpredictability in the training we try to provide more elaborate frames, requiring sense-making and learn the pilots to re-frame. We compare this to a training that is made to resemble the one-sidedness and predictability of the potentially 'bad' industry practice. The group that received the predictable training will be referred to as Group 1, the group that received the unpredictable training will be referred to as Group 2.

To test the effectiveness of the training, all participants perform two test scenarios involving a surprise situation. The first one is unrelated to the training. The second one is related to the training, but it is more elaborate and involves the application of what was learned during training in a different context.

We expect that there is a benefit in providing unpredictability in the training. Therefore we expect that in the training-related surprise tests, the pilots in Group 2 perform better than the pilots in Group 1. It is not expected that the short training will result in a difference in performance in the surprise test which is unrelated to the training. However, due to the unpredictability, the need for sense-making and the selection and execution of actions, the pilots in Group 2 are expected to indicate a higher mental workload during training than those in Group 1, who focus on the execution of actions.

II. Training design for unpredictability

As was proposed, a possible solution to better prepare pilots for surprise situations is to train with unpredictability. This section gives the differences between the two trainings and states why this adds to the unpredictability for one of the groups. The aircraft model used in the experiment is then briefly discussed. The section ends with the training scenarios used in this experiment. The training given to the participants is what makes the difference between the two groups in this experiment.

A. Differences between the two trainings

The training given to Group 1 and Group 2 differs in three ways, affecting different aspects of the training. Together, these differences make that Group 1 knows what is coming, and can therefore already make a strategy. They are already in the right frame. Contrary to this, Group 2 has less information on what is coming and first needs to identify the situation. By incorporating the need for sense-making they are expected to train to build frames and develop re-framing strategies. By providing variations they are expected to extend their frame, resulting in better developed frames [6], [10]. Both groups receive equal attention during the experiment, performing the same number of runs and spending similar time in training.

1) Variety: The first difference between the groups was created by adding variety in the training of Group 2. The International Civil Aviation Organization (ICAO) states in their Manual of Evidence-based Training about the scenario based training phase that: "Wherever possible, consideration should be given towards variations in the types of scenario, times of occurrences and types of occurrence, so that pilots do not become overly familiar with repetitions of the same scenarios." [14, section 1.7.1, p. 61]

In this experiment, variations were added to the wind velocity and direction, turbulence, visibility, instructed velocity and the side, timing and strength of the malfunction. Using these variations, each repetition of the same scenario was slightly different for Group 2. One of these variations was repeatedly presented to Group 1.

By providing the variability, learners can determine the usefulness of variables they rely on in their decision making and focus on those variables that give the most reliable information regardless of the variation [15].

2) Mixed order: The second difference between the groups was in the order in which the scenarios were presented. Group 1 received each topic grouped and in order. For Group 2 the scenarios were mixed, with only two consecutive runs of the same training scenario.

By providing spacing between the equal scenarios, the pilot could not simply assume that the following problem was based on the immediately preceding scenario. In each run, the pilot was therefore required to identify the situation and determine an appropriate response to the problem.

Studies found that mixed practice increased the judgments of problem difficulty [16], [17]. Therefor a higher mental workload is expected for Group 2, compared to Group 1.

3) Instruction: The third difference between the groups was in the timing of the instructions. Group 1 was given the scenario details and instructions before the first run. This included the task to be performed, the wind condition, the malfunction, the timing of the malfunction and the appropriate response. Group 2 received less instructions before the first run of a training scenario. The same instructions for the task and wind condition were given, without information on the malfunction, the timing of the malfunction and the appropriate response. They were only informed that a malfunction would happen to which they had to respond appropriately. After the first run, and before the scenario is repeated, information was given on the malfunction and the appropriate response. Group 2 was never given information on the timing of the malfunction.

The idea is that with more info before the training, the focus is on the task and less on the situation. While instructions are given at different moments, participants in both groups receive the same information.

This difference is based on constructivism, the information and level of assistance given to the student. The constructivist approach opposes the paper-based, rote memorization and teacher-led model, and propose a system whereby the instructor instead poses questions, problems or scenarios. Two examples based on the constructivist learning theory are problem-based learning [18], [19] and discovery-based instruction [20]. These learner-centered approaches are meant to emphasize the learner's critical role in constructing meaning from new information and prior experience. The idea is that by discovering for oneself, the acquired knowledge is more viable in the identification and solving of later problems.

B. Aircraft used

The elements trained were all focused on yaw control, training the engine and rudder control and their relation. For the aircraft model a non-linear flight dynamics model of the Piper Seneca III was used [21]. A twin propeller aircraft with wing-mounted engines has many interesting features. Due to the engine placement, asymmetric thrust generates large yaw moments. The induced flow of each propeller over the wing creates extra lift, which in the case of asymmetric thrust generates a roll moment. This roll moment is especially strong at low airspeeds. Additionally the aircraft has a noticeable adverse yaw effect. The effectiveness of control surfaces

TABLE I
TRAINING: SINGLE ENGINE FAILURE ON TAKE-OFF VARIATIONS

	Timing	Engine
Variation 1	Gear leaver up	Left
Variation 2	65 knots	Right
Variation 3	Rotate	Right
Variation 4	270 ft	Right
Variation 5	Gear halfway up	Left
Variation 6	310 ft	Right

TABLE II
TRAINING: RUDDER HARDOVER ON APPROACH VARIATIONS

	Timing	Deflection	Wind	Turbulence
Variation 1	20 seconds	15	270°	None
Variation 2	50 seconds	20	180°	None
Variation 3	50 seconds	25	90°	Light
Variation 4	30 seconds	10	270°	Light

TABLE III
TRAINING: SINGLE ENGINE FAILURE ON APPROACH VARIATIONS

	Timing	Engine	Wind	Turbulence
Variation 1	20 seconds	Left	270°	None
Variation 2	40 seconds	Right	270°	Light
Variation 3	30 seconds	Left	90°	None
Variation 4	50 seconds	Right	90°	Light

depends on the airspeed, resulting in a minimum airspeed for control authority when flying with one engine inoperative [22].

This type of Multi-Engine Piston (MEP) aircraft is part of the initial pilot training for the Multi-engine Rating. By using this aircraft we place experienced pilots in an unfamiliar situation, as they are not current with the specific handling characteristics of a twin propeller aircraft. By combining this aircraft and the training scenarios, we expect to be able to see a difference in performance after the short training.

C. *Training scenarios*

A total of 14 training runs were performed by each participant, divided over three malfunction scenarios: (a) a single engine failure during take-off, (b) an engine failure in approach, followed by a low speed flyby over the runway, and (c) a rudder hardover in approach, also followed by a low speed flyby over the runway. The first scenario was performed six times, the other two were each performed four times. The first scenario was performed two additional times to give Group 1 an engine failure at two different times: one in climb and another before reaching the decision speed. The wind strength was either light (6 to 10 knots) or moderate (14 knots) and was indicated before each run as well as by a windsock next to the runway.

The first training scenario trained the response to an engine failure in take-off or initial climb. If the malfunction happened beyond the decision speed of 80 kts, or when the take-off was not rejected, a single engine climb of approximately 200 ft was performed. To climb with one engine required all power from the remaining engine as the aircraft has almost no reserve power. The scenario started on the runway with 3000 ft of runway available for take-off. This distance is sufficient for the aircraft to take-off, but prevents that a landing can be made on the runway after an engine failure. The pilot was instructed to take-off and fly a circuit as was done during the familiarization. During the take-off one engine failed. The variations differ in the moment of the engine failure and on which side the engine fails, see Table I. All variations contained a light crosswind, which was constant between all variations. Training scenarios for Group 1 were limited to the first two variations, each of these was repeated three times in a single block. Group 2 performed each variation once, divided in three blocks with two repetitions each.

The second training scenario started on approach with the aircraft in approach configuration and the runway straight ahead. The pilot was instructed to fly to the runway and perform a flyby over the runway centerline at an altitude of 100 ft and a minimum airspeed of 85 knots. During the approach a fixed rudder deflection was introduced. With this malfunction a flyby was performed over the runway centerline, requiring precise control over the aircraft. At an altitude of 100 ft, the runway provides clear visual information to the pilot on the position and attitude of the aircraft. Group 1 was informed beforehand that the rudder deflection could be compensated using differential thrust. Group 2 was only given information on the malfunction and the use of differential thrust after performing this scenario once. The variations are in the timing of the malfunction, the deflection angle, the wind direction and the addition of light turbulence in some variations, see Table II. Additionally, variations 3 and 4 contain a reduced visibility of nine kilometers, just enough to see the runway from the location where the scenario started. Group 2 was given the extra instruction to increase their airspeed at the halfway point of the runway. In all variations the malfunction happened before the runway was reached. Group 1 performed the first variation four times. Group 2 performed each variation once.

The third and final training scenario involved the same task as the second training scenario, but instead of a rudder malfunction, a single engine failure was given. Instructions for Group 2 were the same as what they received for the second training scenario. Group 1 was also informed about the failure that would be practiced. The instructed minimum airspeed of 85 knots was important in this scenario, as for lower airspeeds the rudder authority becomes insufficient to compensate for the yaw moment caused by the thrust asymmetry. The variations are given in Table III. Additionally, variations 3 and 4 have reduced visibility. Group 1 performed the first variation four times, while Group 2 performed each variation one time.

Figure 1 shows the order in which the scenarios and variations are presented to the two groups. The letters a, b and c indicate the three training scenarios discussed above. The numbers indicate the variations listed in Tables I to III.

Two subjective measures were used to compare the two trainings. Pilots indicated their mental workload for each train-

Group 1	a1	a1	a1	a2	a2	a2	b1	b1	b1	b1	c1	c1	c1	c1
Group 2	a1	a2	b1	b2	c1	c2	a3	a4	b3	b4	c3	c4	a5	a6

Fig. 1. The training schedules of the two groups, indicating the order, from left to right, in which the scenarios and variations were presented. The letters a, b and c indicate the training scenarios. The numbers indicate the variations.

ing run. For this, the NASA TLX mental demand scale was used, asking the question "How much mental and perceptual activity was required? Were the scenarios easy or demanding, simple or complex?". The indicated values for the 14 runs were averaged per participant to produce one value for the whole training. As part of the post-experiment questionnaire, pilots were asked about their motivation during the training to check whether differences in performance could be attributed to motivation. For this the Interest/Enjoyment factors of the Intrinsic Motivation Inventory (IMI) were used, consisting of seven questions.

III. Method

This section describes the pilots who participated in the experiment and the composition of the two groups over which they were divided. This is followed by the apparatus used and the experiment procedure. The section ends with a description of the scenarios used for testing the pilot performance, which were equal for all participants.

A. Participants

For this study, 21 airline pilots, 11 captains and 10 first officers, participated on a voluntary basis (mean age: 41.2 years, SD = 8.70; mean flying experience: 17.1 years, SD = 7.95; mean flight hours: 8677, SD = 5623). The experience expressed in total flight hours ranged between 1200 and 18000. The average experience on Multi-Engine Piston (MEP) aircraft, comparable to the model used in this experiment, was 73.3 hours (SD = 129). The median was 25 hours. Three participants had over 50 hours of MEP experience, with a maximum of 550 hours for one participant. One participant indicated zero hours of MEP experience.

Participants were randomly placed in the two groups, unless the balance was threatened. Three participants were therefore manually assigned to Group 1: two instructors and one pilot with extended MEP experience. Group 1, the predictable training group, contained 6 captains and 5 first officers for a total of 11 pilots. Group 2, the unpredictable training group, contained an equal 5 captains and 5 first officers for a total of 10 pilots. Four participants were also active as training instructor. Two instructors were placed in each group.

Table IV gives a comparison of the groups. The probability value (p) was obtained using an Independent-Samples T-test. The test shows that the means of the two groups are not statistically different from each other (using significance level alpha = .050).

The table shows that the mean MEP hours differ with more that a factor 2 between Group 1 and Group 2 and the standard deviation differs with a factor of over 3. This is caused by two outliers with extended MEP hours.

TABLE IV
Group comparison: Participants

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Age (years)	41.1 (8.89)	41.3 (8.96)	.958
Experience (years)	15.9 (7.06)	18.4 (9.02)	.487
Total hours	7362 (4409)	10285 (6747)	.283
MEP hours	43.6 (52.1)	106 (179)	.311

Before the experiment the participant were informed of their rights both in writing and verbally and all participants signed a consent form. When seated in the simulator they were again told that their contribution was voluntary and that they could stop at any moment without stating a reason.

As all participants and researchers were Dutch, the experiment was performed in the Dutch language. The questionnaires were in English, as some of the scales were only validated in English.

B. Apparatus

The experiment was performed in the SIMONA Research Simulator (SRS) located at Delft University of Technology, Faculty of Aerospace Engineering. The SRS has a six-degrees-of-freedom hydraulically driven motion system[1] [23].

Participants were seated in the right seat, using a right-handed side-stick with pitch trim for pitch and roll control. The rudder pedals were equipped with a control loading system. The mid-console provided the throttles for both engines and the flap selector. Only the flaps up and 25° setting were used. In front of the pilot a primary flight display and engine information display were provided, see Figures 2 and 3 respectively. The gear was operated using a central lever left of the engine display. No further switches, buttons or controls were required to be used by the pilot during the experiment.

The pilot was not assisted by flight automation or automated warning systems. What was included was propeller auto pitch and feather, only requiring throttle control to set the engine power.

The cockpit of the simulator does not resemble the cockpit of the aircraft used in the simulations. As this experiment is not a training program for this particular aircraft, the SRS cockpit with the above mentioned control inputs and displays provides what was required to perform this study.

Outside visuals include Precision Approach Path Indicators (PAPIs) for the approach and wind socks at each end of the runway give information on the wind conditions. Engine sound is provided over the headset. However, as the headset is mono the tracks for each engine are mixed together and there is no audible information on which track corresponds to which engine.

To make sure that all participants were presented with the same scenarios under the same conditions, a system was created to automatically play the scenarios in the simulation.

[1]One participant, a captain in Group 2, performed the experiment without motion due to a malfunction of the motion system of the simulator.

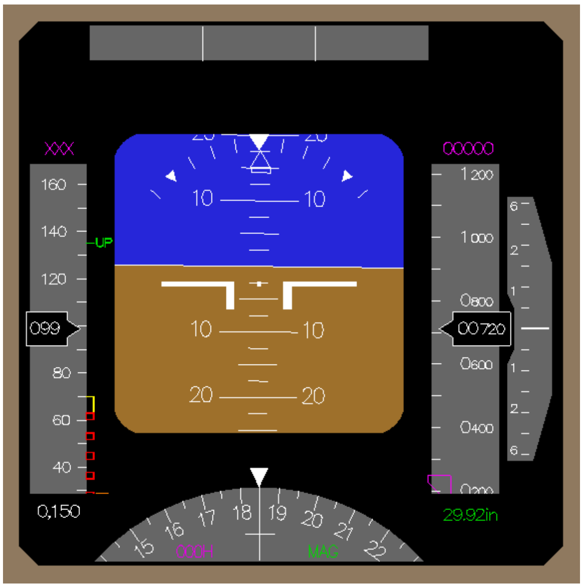

Fig. 2. Primary flight display presented to the pilots during the experiment.

C. Procedure

The experiment took about two hours per participant, starting with a briefing and ending with a final questionnaire. The time in the simulator was about one and a half hours, of which one hour was spent flying the aircraft in the different scenarios. Apart from the surprise tests, all scenarios are performed on Schiphol runway 18C. There is no other traffic in the simulation.

1) Briefing: All participants received an introduction to the experiment right before the start of the experiment. They were told they are participating in a training methods experiment with scenarios containing technical malfunctions, influencing the controllability of the aircraft. Pilots were requested to perform the task given, and continue doing so after they noticed a malfunction. Participants were also asked to give an immediate call-out when they notice something with the aircraft, together with what they thought of as being the problem. The call-out was answered with a neutral "Check" to not give information on the correctness of the ideas of the pilot before the scenario was finished.

The briefing further included information on the Piper Seneca III used as the model, the available control inputs, and details on the familiarization phase. While seated in the simulator, the pilots were shown the controls and the displays used during the experiment.

The participant wore a headset with open mike for direct verbal communications. The engine sound provided over the headset did not obstruct voice communications.

2) Performed scenarios in the simulator: Figure 4 gives an overview of the different steps performed in the simulator, together with the average time in control for all pilots.

To let the participants familiarize with the aircraft controls and the environment, two familiarization runs were performed which did not contain a malfunction. Starting on the runway, the pilots performed a left-hand circuit at 1000 ft. During the downwind leg participants were told to try out the controls. The airspeeds given were: rotate speed of 80 kts, climb speed of 92 kts, a cruise speed of 130 kts and an approach speed of 85 kts. The climb speed is the same in case of an engine failure. The take-off was to be performed with full throttle and without flaps, while for the approach and landing a flap setting of 25° was used. The first familiarization flight was done in a nominal situation without wind. This same scenario was repeated with moderate crosswind.

After the familiarization a pre-test was performed to obtain a baseline performance measure. This was followed by a training depending on the group the participant was assigned to. Each time after performing two training runs, the participants filled in their mental demand for the two scenarios individually, using the NASA TLX mental demand scale. Following the training two surprise scenarios were presented to all participants to test the effect of the training. The first surprise scenario was unrelated to the training and meant to offer a different context before the second surprise scenario, which was related to the training. The simulator session ended with the post-test, which was equal to the pre-test.

If the pilot lost control over the aircraft during any of the runs, the simulation was stopped and the next scenario loaded. The pilots were free to take a short break before starting the next scenario if needed.

3) Afterwards: After leaving the simulator, pilots filled in a questionnaire about the two surprise scenarios. To conclude the experiment all pilots were debriefed. They were informed which of the two trainings they were given, the purpose of the experiment and the expected outcome of the study. Participants were free to ask questions and feedback was given when requested.

D. Pre- and post-test

The pre-test was used to obtain a baseline performance measurement for the manual flying skills of the participants. This score was used to check the balance between the two groups. The post-test, the last scenario flown, was equal to the pre-test and used to compare manual flying performance before and after the training. It is expected that both trainings have an equal effect on the pilots in the two groups.

The scenario started in approach and contained moderate crosswind conditions. Pilots were instructed to approach the runway and make a landing. During the approach the rudder would become fixed in the neutral position. As this also disabled the nose-wheel steering, the pilots were instructed to make a nose-up landing.

Pilot performance was scored using three measures:

- the RMS of the centerline deviation during the last 60 seconds before landing,
- the touchdown location offset from the centerline, and
- the RMS of the aileron control inputs given during the last 60 seconds before landing.

E. Unrelated surprise test

The unrelated surprise test contained an increasing offset between the actual and the indicated airspeed. This malfunction is unrelated to the trained malfunctions. This test was initially

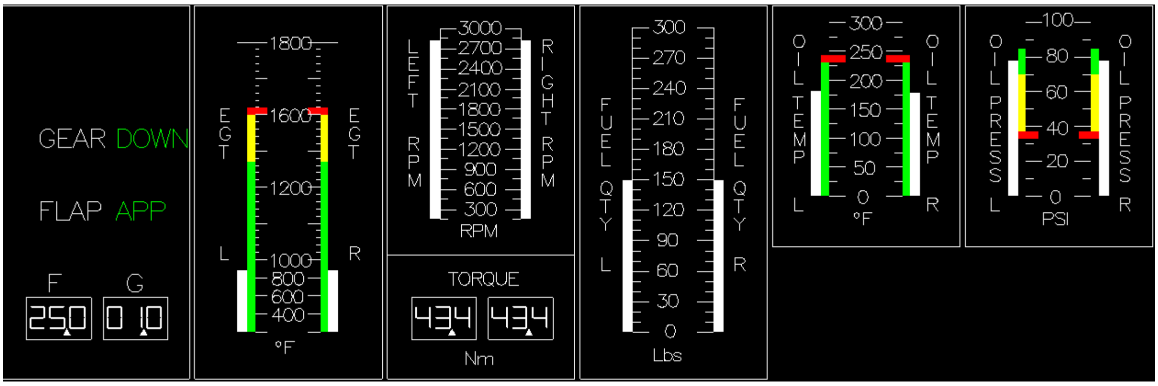

Fig. 3. Display with engine information presented to the pilots during the experiment, located in the place of the Navigation Display left of the PFD. The display gives information on (from left to right): landing gear and flaps position, exhaust gas temperature (EGT), engine RPM and torque, fuel quantity, oil temperature and oil pressure.

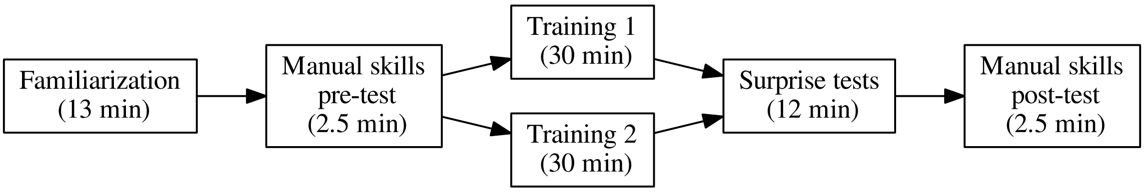

Fig. 4. Overview of the steps performed in the simulator, together with the average total flight time per participant.

meant as an unrelated scenario between the training and the related surprise test, to take the pilots out of the training context and to give both groups the same scenario before the test. During the execution of the experiment it became clear that this scenario could give interesting results.

To differentiate from the training this scenario is performed at another airport than where all previous scenarios took place. The scenario starts on runway 05 of Lelystad Airport and contains moderate crosswind conditions.

The pilot is instructed to again fly a left-handed circuit at 1000 ft and respond to a problem. After liftoff the indicated airspeed starts to drop with 1 knot per second compared to the actual airspeed. Initially the pilot will try to keep the airspeed constant and compensate by relaxing the elevator pull, resulting in a lower rate of climb. To the pilot this could indicate limited engine performance or additional drag, instead of a problem with the indicated airspeed. While the indicated speed continues to drop and the actual airspeed increases, pilots have to focus their attention away from the airspeed indicator to realize the indicated value is incorrect.

After giving a call-out, pilots were instructed to continue the circuit and perform a landing without airspeed indication. A good response to this malfunction is defined by:

- the airspeed may not exceed 135 kts (the maneuvering speed) below 500 ft,
- the landing speed may not exceed 100 kts, and
- a landing is performed on the runway.

Performance was quantified by checking whether pilots met all three criteria or not.

F. Training-related surprise test

The related surprise test contained a combined malfunction to one engine and the rudder. In the training program, both a malfunction of an engine and a malfunction of the rudder has been trained separately. In all cases, either an engine or the rudder failed completely and instantly. The pilot had to compensate the engine failure using the rudder and the rudder failure by applying differential thrust on the engines. However, in this scenario the malfunctions presented themselves in a different way from how they were trained.

The scenario starts the same as the unrelated surprise test, on the same airport, under the same conditions and pilots are provided the same instructions. This is done to give the participants the idea that the same scenario will be repeated again, as during the training all participants were provided the scenarios in blocks of three or four the same (Group 1) or two comparable (Group 2) malfunctions.

In this test however, there is a gradual reduction in the available power from the right engine, starting during the take-off roll. This slowly developing asymmetric thrust situation had to be compensated by the pilot by providing rudder and aileron inputs. As the situation changed slowly, there was no clear indication of a problem until pilots noticed the limited performance and/or realize how much control input they had to give to keep the aircraft under control and on course.

During the climb, at an altitude of 490 ft, there was a short loss of power on the good engine, presenting the pilots with a moment[2] of limited performance on both engines. After the hick-up pilots were told that both engines are unreliable,

[2]This events takes seven seconds in total. Consisting of four seconds of decreasing power, two seconds with minimal power and another second to return to full power.

and that both should be used. This was done to prevent that some pilots would close the throttle of the engine with limited power, thereby increasing the thrust difference between the two engines and taking away the possibility to operate the two throttle levers independently. They were instructed to climb to a reduced altitude of 800 ft and continue the circuit.

When rolling out of the turn into the downwind leg, a second malfunction was introduced by reducing the aileron effectiveness. This malfunction resulted in less yaw moment available from the rudder to compensate the thrust asymmetry. Pilots were instructed to continue the circuit and land on the runway, or if that was not possible, close to the runway.

Two moments are used to compare pilot performance. The first was related to the rudder input in response to the engine hick-up, comparing three items:

- the response time to initial rudder input (one degree in either direction),
- the direction of initial rudder input (additional or reduced deflection), and
- the response time to additional rudder input, also taking into account the direction of input (three degrees reduced deflection).

The second measure depends on the outcome of the scenario. To perform well the pilot had to:

- keep control over the aircraft, and
- perform a landing on the runway.

G. *Statistical analysis*

The effect of the training on the performance in the surprise tests was tested using Pearson's Chi-squares test. The pre- and post-test are compared using a Multivariate ANOVA. Other tests were performed using an independent-samples T-test. The significance level of all analyses was set at alpha = .050.

IV. Results and Discussion

This section presents the results of the experiment and indicates how this relates to the hypotheses.

A. *Time spent in control*

Table V gives the total time spent in control of the aircraft during different parts of the experiment. The data was analyzed using an independent-samples T-test to compare the two groups. Although pilots had some freedom in performing each of the scenarios, especially the familiarization and the surprise tests, both groups spent a comparable time controlling the aircraft to perform the different scenarios.

Figure 5 focuses on the total time spent in control of the aircraft during the 14 training runs. Both groups spent an average of 29.8 minutes in control. The unpredictable training groups showed a greater variance in the time taken to perform the training scenarios. The data shows that equal training time was given to both groups.

TABLE V
Group comparison: Time in control in minutes

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Familiarization	13.2 (1.55)	12.5 (1.55)	.337
Training	29.8 (.883)	29.8 (1.57)	.996
Surprise tests	13.2 (2.63)	11.7 (3.10)	.228
Total	61.1 (3.79)	59.0 (5.54)	.323

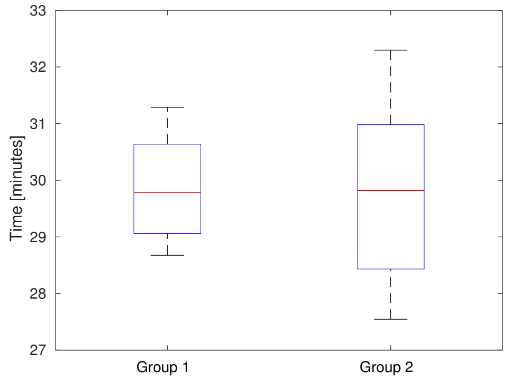

Fig. 5. Comparison between the two groups of the total time spent in control during the training, in minutes

TABLE VI
Group comparison: Pre-test

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Centerline	5.74 (2.80)	4.55 (2.20)	.296
Landing	2.54 (3.26)	2.15 (1.81)	.737
Aileron	2.83 (1.42)	2.93 (1.73)	.891

TABLE VII
Group comparison: Post-test

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Centerline	5.64 (3.39)	5.83 (3.75)	.907
Landing	2.88 (2.56)	1.64 (1.33)	.189
Aileron	4.42 (2.97)	5.05 (4.34)	.704

B. *Pre- and post-test on manual skills*

Table VI gives the group comparison resulting from the pre-test. Measures of the participants resulting from the pretest were compared separately with an independent-samples T-test, to check whether the groups were comparable in manual skills. The statistical test shows there is no significant difference between the groups when comparing these measures individually.

The same test was repeated at the end of the experiment. Table VII gives the results from the post-test.

When comparing the scores between the pre-test and the post-test, multivariate testing revealed that there was a significant effect of Time on performance, Roys largest root = .564, F(1,19) = 3.194, p = .050. There was no significant effect of

TABLE VIII
GROUP COMPARISON: SUBJECTIVE MEASURES OF TRAINING

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Mental workload (5-100)	42.8 (15.1)	49.7 (11.3)	.257
Interest/Enjoyment (7-49)	44.0 (3.97)	42.8 (6.63)	.631

Training (Roys largest root = .073, F(1,19) = .416, p = .743) and no Training x Time interaction effect (Roys largest root = .243, F(1,19) = 1.375, p = .284). This means that, for the measures used, which training is given does not influence the performance. Univariate testing (Greenhouse-Geisser) showed that for the measure of aileron usage, there is a significant difference between the pre- and post-test, F(1,19) = 8.546, p = .009. Both groups show an increase in this control activity measure in the post-test compared to the pre-test, see Tables VI and VII.

C. Training

It was expected that adding unpredictability in training would lead to an increase in mental workload. On average, participants in Group 2 indicated a higher mental demand (M = 49.7, SD = 11.3) than those in Group 1 (M = 42.8, SD = 15.1). This difference was not significant, p = .257. Based on these results we cannot say that the unpredictable training increased the mental workload during training, compared to the predictable training.

To check whether differences in performance could be attributed to motivation, pilots were asked for their motivation during the training. On average, participants in Group 1 indicated a higher motivation (M = 44.0, SD = 3.97) than those in Group 2 (M = 42.8, SD = 6.63). This difference was not significant, p = .631. As the scale ranges from 7 to 49, both groups indicated a high motivation.

Table VIII summarizes the results of the subjective measures.

In the second training scenario, containing the rudder hardover, there was one loss-of-control event during the flyby. This happened during the first run of a participants in Group 2. In the third training scenario, containing a single engine failure, there were two loss-of-control events during the flyby. This also happened for two participants of Group 2, both during the first run of this training scenario.

As part of the rudder hardover training, participants were instructed to use differential thrust. Group 1 was given this instruction before the first run while Group 2 received the instruction after the first run. During this first run all the pilots in Group 1 made use of differential thrust, while three (N = 10) pilots in Group 2 already made use of differential thrust on their own initiative. For the subsequent three training runs of the rudder hardover training all participants made use of differential thrust.

What was also interesting to see was that some participants ignored the rudder when they knew the rudder could not be controlled. This is only useful during the training and something unpredictable training can prevent.

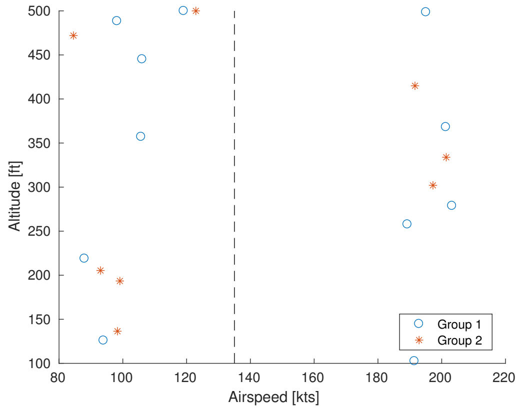

Fig. 6. Unrelated surprise test: The maximum obtained airspeed under 500 ft and the corresponding altitude at which this speed was reached. The dashed line indicates the maximum allowed airspeed of 135 kts.

D. Unrelated surprise test

Good performance in the unrelated surprise test was defined using three requirements. The first requirement was that the airspeed may not exceed 135 kts below 500 ft. The maximum obtained airspeed under 500 ft and the corresponding altitude at which this speed was reached are shown in Figure 6. The figure shows a clear division in pilot response, based on the maximum airspeed obtained. On the left all pilots obtained airspeeds between 85 and 123 kts, while at the right side of the graph pilots reached much higher airspeeds between 189 and 203 kts. These high airspeeds indicate attempted emergency landings without realizing the airspeed is incorrect. Only 18 data points are shown, as for three participants the simulation stopped due to errors during the execution of this scenario. This happened with one participant from Group 1 and two participants from Group 2. At the time of the error participants already experienced the surprise situation, thus the scenario was not restarted.

The second requirement was that the landing speed may not exceed 100 kts. There were two occurrences of a high speed landing, both by pilots from Group 2. In both cases the landing speed was above 135 kts, thus both already did not satisfy the first performance requirement. The other participants who reached an airspeed over 189 kts under 500 ft realized their airspeed was more than indicated before reaching the ground, and subsequently pulled up and continued the circuit. The third requirement was that a landing was performed on the runway. This requirement did not change the outcome of this test.

Based on these three requirements, 6 out of 10 participants from Group 1 and 5 out of 8 participants from Group 2 showed good performance. Statistical analysis shows no significant effect of the training on the performance in this scenario (p = .914, Chi-Square = .012). Therefore we cannot state that adding unpredictability in training results in better performance in a surprise scenario which is unrelated to the trained topic.

During this scenario the participants initially indicated that they though of reduced engine power or additional drag as the cause of the problem, citing the combination of a low airspeed

TABLE IX
RELATED SURPRISE TEST: RUDDER RESPONSE TIME IN SECONDS FOR A DOUBLE ENGINE POWER REDUCTION IN CLIMB

	Group 1	Group 2	
	Mean (SD)	Mean (SD)	p
Initial response	2.71 (1.36)	2.66 (1.11)	0.928
Additional response	3.69 (0.91)	3.53 (0.84)	0.694

TABLE X
RELATED SURPRISE TEST: OUTCOME OF THE SCENARIO

	Group 1	Group 2	Total
Landing on runway	2	9	11
Offsite landing	4	1	5
LOC-I	5	0	5
Total	11	10	21

and low climb rate.

Some participants noticed early that something was wrong with the airspeed indication, citing that the plane did not feel as if it was about to stall. These participants were able to make sense of the situation and re-frame [6], [10]. Other participants focused their attention on the airspeed indicator and fully concentrated on flying back to the runway as quickly as possible. Only when they reached a low altitude, or after landing, did they notice their indicated airspeed was off.

E. *Training-related surprise test*

Two sections of the related surprise test were analyzed to come to a measure of pilot performance. The first is related to the rudder input in response to the engine hick-up. Table IX shows the response time for initial rudder input and additional rudder input. The initial response is based on a change in rudder deflection of one degree in either direction. The additional response is the time until a three degree reduction in rudder deflection was given, thus also taking into account the direction of the given input. As the yaw moment due to the asymmetric thrust reduces, less rudder is required to compensate. Two participants from Group 1 initially gave more rudder input, to reduce again some seconds later (2.7 and 5.3 seconds). An Independent-Samples T Test shows no significant effects of the training on the response time. It can therefore not be stated that adding unpredictability in training reduces the response time.

Two data point were missing. One participant from Group 2 did not change the rudder input at all, while one participant from Group 1 did give less rudder, but only two degrees less.

The second performance measure for this scenario is how pilots handle the combined engine and rudder limitation. In total 11 out of the 21 pilots performed a landing on the runway, thereby reaching the objective of this scenario. However, out of these 11 cases, 9 were from Group 2 and only 2 were from Group 1. Statistical analysis shows a significant effect of the training on the performance in this scenario ($p = 0.01$, Chi-Square = 10.83). Based on this result we can state that in a surprise situation which is related to the given training, the addition of unpredictability in the training improves pilot performance.

Of the pilots that did not make it to the runway, five performed an offsite landing. Four participants were from Group 1, of which three came into problems on approach and one already landed in the downwind leg. Only one participant from Group 2 did not make a landing on the runway, running into problems on approach and performing a landing off to one side of the runway.

The five remaining participants experienced Loss of Control In-Flight (LOC-I) from which they could not recover in time. All of these participants were from Group 1. This means that none of the participants who were given the unpredictable training experienced an unrecoverable loss of control.

These results of the related surprise test are summarized in Table X. The outcome of this scenario indicates that the training with unpredictability better prepared pilots than the predictable training.

Pilots lost control when the airspeed decreased so far that the rudder authority was not enough to compensate the thrust asymmetry. In this case the aircraft would yaw and roll to the right. If enough altitude was available pilots could get the aircraft back under control by pushing the nose down, trading altitude for airspeed. Giving throttle to increase the airspeed would increase the thrust asymmetry, making the situation worse.

In the cases which went wrong late in the approach, there was not enough altitude to increase the airspeed. Pilots would either do their best to keep the aircraft under control and make a controlled offsite landing right of the runway, or close the throttle to decrease the thrust asymmetry.

Pilots who successfully landed either made an approach with an airspeed above the approach speed, came in high with little thrust or made a flapless landing.

One participant forgot to take the landing gear up, thereby requiring less configuration change before landing. This pilot was one of the two from Group 1 who made a landing on the runway.

F. *Indicated level of surprise*

After the experiment participants indicated their level of surprise on a scale of 1 (not at all) to 5 (extremely) for three events. For the related surprise test, participants indicated their surprise for two parts of the scenario. The first part relates to the take-off and the problems with the engines and the second part relates to the introduction of the decreased rudder effectiveness and the following flight. For the unrelated surprise test the surprise due to the airspeed offset was asked. The indicated surprise levels are given in Table XI.

For all three events, Group 1 indicated to be more surprised than Group 2. Only the surprise due to the engine problems shows a significant difference, $p = .041$.

V. CONCLUSION

The expectation was that in the training-related surprise tests, the pilots in Group 2 would perform better than the

TABLE XI
INDICATED SURPRISE LEVEL (SCALE 1 TO 5)

	Group 1 Mean (SD)	Group 2 Mean (SD)	p
Airspeed offset	3.67 (0.50)	3.20 (0.92)	0.185
Engine problems	2.73 (0.65)	2.20 (0.42)	0.041
Rudder effectiveness	3.45 (0.69)	2.89 (1.17)	0.223

pilots in Group 1, because they have more elaborate frames and already practiced sense-making and re-framing during training. The results show that Group 2 indeed performed better than Group 1. Pilots from Group 2 who successfully landed either made an approach with an airspeed above the approach speed, came in high with little thrust or made a flapless landing. These strategies indicate they had superior understanding of the effects of the single engine failure and of measures required to counter it. They can thus be said to have more developed frames of the matter due to the training. Five participants from Group 1 completely lost control over their aircraft in-fight. This did not happen to any of the participants in Group 2, supporting the benefit of unpredictability and variety training.

In the situation with an airspeed indicator problem, which was unrelated to the training, no benefit of unpredictability in training was found. This was expected, since the training provides no specific information to built frames related to this situation. It is possible that additional flight time, especially at higher airspeeds and altitudes, could have changed the outcome of this test. Pilots who did not notice the problem on time indicated that they missed the wind noise around the aircraft, and therefore did not realize their airspeed was much higher than the indicated value. The pilots that showed good performance in this scenario were able to make sense of the situation and re-frame. We can however not say that this was due to the training.

Due to the limited simulator time available and the malfunctions faced during each run, except the familiarization runs, it was clear that in the two surprise tests another malfunction would happen. Therefore the pilots could not be surprised with the fact that a malfunction happened, they could however be surprised with what would happen and what effect this would have on the aircraft. The subjective measures of the pilot's level of surprise showed that the test scenarios were indeed successful in providing surprising situations.

Due to the unpredictability, the need for sense-making and the selection and execution of actions, the pilots in Group 2 were expected to indicate a higher mental workload during training than those in Group 1, who focus on the execution of actions. The measures for the training phase showed no significant difference on pilot's indicated mental workload. This indicates that it is not more demanding for the pilots to add unpredictability and variety in the training. It is possible that this is due to the limited time required for re-framing, compared to the total duration of each training scenario.

The participants were divided in two well-balanced groups, both in terms of experience and performance. In the unrelated surprise test 61% of participants showed good performance and for the training-related surprise test this was 52%. This is a good balance between the pilots that did and did not show good performance, indicating the right level of difficulty was obtained in these scenarios.

This study shows that there is a benefit in adding unpredictability and variety in scenario-based simulator training to improve pilot performance in surprise situations. The outcome thereby supports the recommendations of aviation authorities that surprise should be included in upcoming simulator based LOC-I prevention training [7], [8], [12].

Further research is required to find the individual effect of the methods used to add unpredictability (variety, mixed order, instruction), the right level of unpredictability and the right training phase in which to introduce unpredictability and variety to make optimal use of this benefit.

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Part II

Preliminary report

Chapter 1

Introduction

Today pilots are better trained than ever, and they have assistance from automation and advanced tools for control, navigation and communication. At the same time the aircraft and these systems have become more reliable. This has led to a decrease in the number of accidents and fatalities. However, the increased level of automation resulted in limited flying practice during operations. Inappropriate actions made by the flight crew are mentioned in a majority of accident report as the main cause or a contribution to the accident (Belcastro & Foster, 2010; Lambregts, Nesemeier, Wilborn, & Newman, 2008; Shappell et al., 2007).

Training of pilots for abnormal events (e.g. stall, engine failure, wind shear) is performed in simulators. Research indicates that the current pilot simulator training, as mandated by the authorities, is not sufficient in preparing pilots for the range of situations that can occur in normal operations (Casner, Geven, & Williams, 2013; Rankin, Woltjer, Field, & Woods, 2013; Schroeder, Bürki-Cohen, Shikany, Gingras, & Desrochers, 2014). The training is too predictable as variations are brought to a minimum, with a focus on predetermined responses to events that, in the context of the training, hardly come as a surprise. Time available for training is limited. For an airline the most expensive pilot is a pilot in training. As the pilot is not flying this means he or she does not contribute to making a profit, while at the same time the salary continues and the training costs have to be payed. Therefore the time spent on training has to be used optimally. In most cases, this means the time available for training is spend mainly on what is tested.

The goal of this research is to find recommendations to improve airline pilot training methods, leading to a better training of flight skills in a way that is transferable to scenarios different from those explicitly trained. Leading to better use of time and resources to best prepare the pilot, not just for the test pilots have to perform, but the situations they can face in the day-to-day operations. Also important in the training is to give the pilot the confidence that they can handle the situation, especially when initially they have no idea what is going on and do not feel in control.

For many airlines and training organizations, current pilot simulator training is focused on specific mandatory scenarios, thereby eliminating surprise and the need to identify the event

(Rankin et al., 2013). In this study we try to find if there is a benefit in training with unpredictable scenarios, requiring the recognition of the abnormal event and determining the appropriate response.

According to literature (Carbonell, Stalmeijer, Könings, Segers, & Merriënboer, 2014; Huet et al., 2011; Rohrer, 2009), using variety of training has the following benefits:

- Broader understanding, a better mental model, of the system and the variables involved due to abstracting a more general set of rules that are consistent in different training examples.
- Learning to better recognize the situation and take appropriate actions.
- Learning to better use the available information, and to ignore irrelevant information.
- As the context is more similar to reality, there is less of a switch required to go from the trained scenario to the real situation.

To test is there indeed is a benefit, a flight simulator experiment is proposed in this document. The goal of this research is to work towards more effective airline pilot simulator training which prepares best for real life situations.

1-1 Research objective

This research aims to find if there is a benefit of unpredictable training over a predictable training in preparing pilots for keeping control over the aircraft in a critical off-nominal situation not explicitly trained. This requires a training for which the trained scenarios can be generalized to additional situations beyond those explicitly practiced.

The main research question is:

What is the effect of unpredictability in training on flight recovery performance in a surprise situation?

This main question is split into the following sub-questions:

1. What are the current training practices for unexpected situations given to airline pilots, and how effective are these in preparing for surprise situations?
2. How do startle and stress, which might result from a surprise situation, affect pilot performance?
3. What methods can be used for making the training less predictable, how have they been used before, and with what result?
4. What are the possibilities of the SIMONA simulator and the Piper Seneca model for use in this experiment?
5. How is pilot performance affected by changing the training method for unexpected situations?

The objective of the research project is to test the effectiveness of pilot training on dealing with unexpected abnormal events by performing a simulator experiment to analyze the effect of two different trainings, differing in their predictability, on pilot performance.

The results of the experiment will be described in a later paper.

1-2 Report structure

Part of the research sub-questions can be answered from current theory. These theoretical research questions will be answered in the literature review in Chapter 2, together with the discussion of other literature found which relates to the topic.

The last sub-questions, and thereby the main question, is answered by performing a simulator experiment in the SIMONA Research Simulator at Delft University of Technology, Faculty of Aerospace Engineering. Chapter 3 describes the non-linear aircraft model that will be used for this experiment, and how this model is incorporated for use on the SIMONA Research Simulator. Chapter 4 discusses requirements for, together with details about, the simulated scenarios for training and testing of the pilots participating in the experiment. The scenarios are implemented in the simulation environment using a new module reading scenario definition files. A Graphical User Interface (GUI) is added for easily selecting the appropriate scenario and to see the upcoming event. Chapter 5 presents the plans for the experiment that is to be conducted to answer the main research question. Finally, Chapter 6 presents the conclusions of this report.

Chapter 2

Literature

In this chapter we look into literature to find answers for some of the sub-questions posed in the previous chapter. Section 2-1 looks into loss of control in-flight, where inappropriate action taken by the crew result in their loss of control over the aircraft. Section 2-2 looks into the airline pilot training and the current shortcomings when it comes to surprise, and if this can explain why pilots loose control. Different methods for improving the training are searched for in Section 2-3. Using these methods to add unpredictability in training, an experiment is defined later in this report to find if there is a benefit in exposing pilots to unpredictability to better prepare them for surprising situations.

2-1 Loss of control in-flight

Loss of Control In-Flight (LOC-I) is the most prevalent cause of fatal accidents in commercial aviation. This is mainly due to the increase in overall safety, whereby other accident causes have decreased.

Accident reports indicate that a large number of accidents involve inappropriate actions made by the flight crew. Shappell et al. (2007) estimated that of air carrier accidents from the years 1990 through 2002, 42.5% involved "pilot skill errors", 39.2% "decision errors" and 5.5% "perception errors". A review of 126 LOC-I accidents occurring between 1979 and 2009 estimated inappropriate crew responses to be involved in 42.8% of accident cases (Belcastro & Foster, 2010).

In their LOC-I Accident Analysis Report, the International Air Transport Association (IATA) defines LOC-I as (IATA, 2015):

> LOC-I refers to accidents in which the flight crew was unable to maintain control of the aircraft in flight, resulting in an unrecoverable deviation from the intended flight path. LOC-I can result from engine failures, icing, stalls or other circumstances that interfere with the ability of the flight crew to control the flight path of

> the aircraft. It is one of the most complex accident categories, involving numerous contributing factors that act individually or, more often, in combination. These contributing factors include latent conditions in the system, external threats to the flight crew, errors in the handling of those threats, and undesired aircraft states resulting from deficiencies in managing threats or errors.

This report analyses operational accidents between 2010 and 2014 for aircraft over 5,700 kg Maximum Takeoff Weight (MTOW). When distinguishing between aircraft propulsion type, turboprop aircraft had a significantly higher average rate of LOC-I accidents than jet aircraft, with 0.68 and 0.09 accidents per million flights respectively. The number of fatalities on the other hand was higher for jet aircraft due to their average larger capacity (875 versus 367).

Lambregts et al. (2008) list a number of causes of LOC-I accidents, based on accidents in the timeframe 1993-2007,

- Aerodynamic Stall (27 cases with 848 fatalities)
- Flight Control System (16 cases with 604 fatalities)
- Spatial Disorientation (8 cases with 630 fatalities)
- Contaminated Airfoil (8 cases with 200 fatalities)
- Atmospheric Disturbance (6 cases with 477 fatalities)

Triggered by an event, the pilots performed an inappropriate action resulting in their loss of control over the aircraft.

2-2 Airline pilot training

An airline pilot requires a Commercial Pilot License (CPL)[1][2]. To obtain this license, initial pilot training starts on a Single-Engine Piston general-aviation aircraft, an aircraft like for example the Cessna 172. This is followed by a brief Multi-Engine Piston training on for example a Piper Seneca. This is accompanied with a theoretical training, the instrument rating, and additional ratings. Each step during the training requires a minimal number of logged hours, some of which can be performed in the simulator, also called a Flight Simulation Training Devices (FSTD). After obtaining the license, a type rating is required to fly a specific large commercial aircraft.

Next to the initial pilot training, periodic training and testing is required for airline pilots. Part of this training is mandatory, where the content and hours to spend in training are defined by the authorities. Additional training is defined by the individual airlines. Recurrent training is performed in the simulator every six months. This periodic training and testing

[1] KLM Flight Academy. `https://www.pilootworden.nl/opleiding/de-opleiding-klm` Retrieved on 26 June 2017.

[2] Vliegopleidingen Rotterdam. `http://www.vliegclubrotterdam.nl/index.php/cpl` Retrieved on 26 June 2017.

can cover a wide range of items on the aircraft, and the airline has the freedom to fill this within a prescribed framework.

The pilot proficiency check is a test of all the knowledge pilots are required to have for daily operations. This check is highly standardized and contains no element of surprise for the pilot. It is like starting the tape and do as was learned. When failing the test, the pilot is grounded until successfully passing another test after additional training is completed. Therefore the most stressful factor might not be what can happen during the scenarios presented, but more the fact that an error might result in the (temporary) loss of the license.

For specific situations, standardized responses are defined. Over time, following the occurrence of particular accidents, there has been additional advice and requirements on training practices. These include, in chronological order and as defined by the FAA & ICAO:

- Manoeuvre-based training (MBT). Training that focuses on a single event or manoeuvre in isolation.
- Scenario-based training (SBT). Training that incorporates manoeuvres into real-world experiences to cultivate practical flying skills in an operational environment.
- Evidence-based training (EBT). Training and assessment based on operational data that is characterised by developing and assessing the overall capability of a trainee across a range of core competencies rather than by measuring the performance of individual events or manoeuvres. (ICAO, 2013)
- Upset Prevention and Recovery Training (UPRT) (FAA, 2017; ICAO, 2014). Training to reduce loss of control events and, if they occur, enable recovery to normal flight.

The International Civil Aviation Organization (ICAO) states in their Manual of Evidence-based Training (ICAO, 2013, section 1.7.1, p. 61); "Wherever possible, consideration should be given towards variations in the types of scenario, times of occurrences and types of occurrence, so that pilots do not become overly familiar with repetitions of the same scenarios." The scenarios are designed to address, as written in the manual "the most relevant threats according to evidence collected in accidents, incidents, flight operations and training."

The U.S. Federal Aviation Administration (FAA), the International Air Transport Association (IATA) and the European Aviation Safety Agency (EASA) are also working on new guidance material for best practices in upset prevention and recovery training.

2-2-1 Effectiveness of airline pilot training

To evaluate the effectiveness of airline pilot training for abnormal in-flight events, Casner et al. (2013) performed an experiment whereby pilots performed three abnormal in-flight events; an aerodynamic stall, a low-level wind shear and an engine failure on takeoff. These events were performed both in the routine ways as seen during training and unexpectedly. This research showed that when pilots were presented with abnormal events in the familiar way as trained, they took the appropriate response in accordance to the accepted standard. The data showed little variability between pilots. However, when the event was presented under less predictable circumstances, pilots' responses frequently differed from accepted standards and showed greater variability between pilots. While the pilots' showed good abilities to respond to the trained versions, these skills do not generalize to other situations.

The participants in this study consisted of 18 active Boeing 747-400 pilots, with an equal split between captains and first officers. Six pilots had a military background, the others were trained exclusively in the civilian environment. The experiment was performed in a Level D 747-400 flight simulator located at the NASA Ames Research Center.

The engine failure event was the same in both the control and the treatment condition. The surprise element was that for half the pilots the event was given during the first takeoff. The engine failure happened when the plain reached a speed of 3 knots over the critical speed, also known as the decision speed or V_1. In this situation the pilot must continue the takeoff.

Each participant saw three stalls, one familiar self-induced power-off stall demonstration as practiced during training and two less expected stalls induced by a rapid wind change. One at 2,500 ft while climbing out after a routine takeoff and the other while descending through 34,500 ft. [3]

The wind shear was presented when descending through 600 ft during approach. For the familiar situation, pilots received information with an explicit warning on wind conditions and a report about a previous aircraft experiencing wind shear. Additionally, the pilots receive an audible alert *"Wind shear! Wind shear!"* from an automated detection and warning system upon encountering the wind shear. In the surprise condition the pilots were not given the advance warnings and the alerting system was disabled.

During the simulator session, captains occupied the left seat and first officers the right seat, per the standard seating location. To perform the experiment with the standard two-person cockpit crew, a copilot was in the other seat and tasks could be delegated to this pilot-not-flying. The copilot did not offer help or advice to the pilot flying.

The simulator session took about 2 hours. During this time the participants performed the 7 events during three complete flights, starting with a takeoff and ending with a landing. During the three legs, also other recurrent normal and abnormal training events were included. The authors state that this is "to avoid the start/stop nature of conventional experiments and preserve the flow of a real flight". No details are provided on what these other events entail and what the effect is on the pilots during these three flights which already contain more events than an average pilot sees in year.

When combining the above details, the following can be set about the experiment scenarios. Each pilot performs three takeoffs, with an engine failure occurring in two cases and in the remaining case a stall during climb-out. Another stall is presented in descent. The two wind shear events are also in descent, but no details are provided if this can happen during the same descent as the stall. The self-induced stall is demonstrated during one of the flight.

The participants were divided in two groups, with each group being given a different presentation order of the events. One group received the engine failure on their first takeoff, and were presented with the familiar versions of the stall and wind shear event prior to seeing these events in the less expected version. The other group first saw the less expected version

[3] While the authors state that the stall demonstration is always performed at low altitudes, typically 10,000 ft, no details are given on the altitude flown at the time the subjects demonstrate the power-off stall during this experiment.

of the stall and wind shear events before the familiar version. This group also saw the engine failure at a later takeoff (it is not specified if this was on the second or third takeoff).

Since this paper was published, the advised standard response for a stall has changed. The current stall recovery template says to push the stick first to move the nose down and increase speed (see AC 120-109; FAA, 2015). The previous advice was to immediately push the throttle to maximum thrust.

The authors suggest to:

- Remove the repetition and add the need for recognizing the situation.
- Add the element of surprise; focus on attentional behavior and sensemaking.
- Turn off automation, to prevent the need for an alert to trigger the responds.
- Change testing procedures, randomizing the skills that are tested.

2-2-2 Role of surprise in training

One of the suggestions given above is to add the element of surprise into the training. In literature and in practice, the terms surprise and startle are often used without a clear distinction between the two (Rivera, Talone, Boesser, Jentsch, & Yeh, 2014). Surprise is an emotional and cognitive reactions, while startle is a quick and uncontrolled reflex.

Surprise is when once expectation does not match with an observation. The expectation follows from one's understanding of the situation or the system. The observation is the interpretation of events and feedback, with the information received by a persons senses. The mismatch can thus be the result of different factors:

- because the expectation is incorrect,
- due to errors in the interpretation of the perceived information, or
- because the presented information is incorrect.

Therefore, when in a surprise situation, it is important to find which of these factors could be the cause of the surprise to come to a new understanding of the situation. Rankin et al. (2013) stated that the crew training is primarily focused on dealing with specific anticipated problems. Unexpected events and how to deal with them is not explicitly addressed.

For each anticipated problem a defined template is available, and checklists are provided on how to deal with malfunctions. However, these procedures do not solve all problems. Haslbeck, Gontar, and Schubert (2014) believe that provided checklists and procedures are not suitable for time-critical situations with abnormal events like technical problems of an aircraft. They believe that the provided abnormal procedures and checklist will emerge as inappropriate in critical situations with time pressure. Due to time limitations, they can either not be accomplished or they won't even be started. Next to this, problems with font sizes, attention errors or misinterpretations are cited as possible causes of error.

In a critical situation where timely and proper intervention is essential, startle and stress have substantial negative effects on attention, cognition, memory, and working memory performance. Martin, Murray, Bates, and Lee (2015) state the importance for airline training programs "to engender a greater sense of self-efficacy among their pilots for handling such critical events, by conducting constructive, reinforcing, and positive training." This way pilots start with a more positive mindset in dealing with a surprising critical events in the case they occur in normal operations. The paper ends with some examples for scenarios that can be used to add more surprise to training.

When performing highly practiced tasks, task performance becomes largely automatic, requiring minimum attention and effort (Dismukes, Goldsmith, & Kochan, 2015). However, in a stressful situation, performance is likely to be undermined. When faced with a threat, resulting in anxiety, the pilot goes from mostly unconscious automated performance to effortful performance which draws heavily on attention and working memory. These two cognitive resources are essential for new or dangerous situations, but performed tasks are typically slow and draws heavily on mental concentration.

Therefor it is thought that adding unpredictability in training can be beneficial to better prepare pilots for new situations, as they already do in the training what is required in new situations.

2-3 Adding unpredictability in training

Training is the process of bringing someone to a set standard of proficiency by practice and instruction. Practice is a search process with modification and perfection, to approach the level of expert. It should not emphasize on reproduction but more on the adaptation to achieve consistent outcome goals.

What is being learned is processed in working memory and stored by constructing schemas in long-term memory (Sweller, van Merrienboer, & Paas, 1998) for later use.

In this section different teaching methods are discussed, together with their benefits and drawbacks as stated in literature. The sections end with some examples of previous experiments on this topic.

2-3-1 Level of assistance in learning

In the common classroom format, a teacher or instructor presents established facts and presents the information in a format that is structured and easy to receive by the student. In the field of pedagogy, there are constructivist approaches that oppose this paper-based, rote memorization, and teacher-led model, and propose a system whereby the instructor instead poses questions, problems or scenarios. Two examples based on the constructivist learning theory are problem-based learning and discovery-based instruction. These learner-centered approaches are meant to emphasize the learner's critical role in constructing meaning from new information and prior experience.

In problem-based learning (Dochy, Segers, Bossche, & Gijbels, 2003; Savery & Duffy, 1995), the student learns by solving open-ended problems. This form of learning was pioneered in medical education, allowing students to see the relevance and application of theoretical material.

Discovery-based instruction (Alfieri, Brooks, Aldrich, & Tenenbaum, 2011), also called discovery learning, is a technique of inquiry-based learning. The student is not provided with an exact answer but rather the materials needed to find the answer themselves. The idea is that by discovering for oneself, the acquired knowledge is more viable in the identification and solving of later problems.

Critique on constructive learning, whereby learners are left unassisted, is that learners need guidance (Clark, Kirschner, & Sweller, 2012; Kirschner, Sweller, & Clark, 2006; Sweller, Kirschner, & Clark, 2007). Novices do not have the necessary skills to integrate the new information with information they have learned in the past. Discovery learning, as an unguided approach to learning, is said to have an overall lack of structure and the risk that incorrect ideas are not corrected. Guided instruction is proposed as a better alternative to discovery learning. However, once the knowledge basis is appropriate discovery can enhance learning.

Alfieri et al. (2011) conclude that unassisted-discovery tasks have limited effect. Enhanced-discovery tasks, which requires learners to be actively engaged and constructive, give a better result. Based on this, the authors suggest optimal approaches of discovery-based instruction should include at least one of the following:

1. guided tasks that have scaffolding in place to assist learners,
2. tasks requiring learners to explain their own ideas and ensuring that these ideas are accurate by providing timely feedback, or
3. tasks that provide worked examples of how to succeed in the task.

With enhanced-discovery tasks, we move away from pure discovery learning and back in the direction of the familiar teacher-led instruction and the guided instruction proposed by (Kirschner et al., 2006).

According to Kirschner et al. (2006), guided instruction produces more immediate recall of facts than unguided approaches, together with longer term transfer and problem-solving skills. Regarding the retention period, (Dochy et al., 2003) concludes that students in problem-based learning gained slightly less knowledge, but remember more of the acquired knowledge.

2-3-2 Adaptive and routine expertise

In a review of research on adaptive expertise, Carbonell et al. (2014) looked at what factors allow individuals to perform at a high level, required to work in a flexible work environment. This is in contrast with routine expertise, which is sufficient in familiar situations.

The required learning format is of the form of the active learning styles, as discussed in Section 2-3-1. Such learning formats provide the possibilities for making errors. If a link is made between the errors and the to-be-learned knowledge, this further benefits adaptive expertise. Establishing this link leads to deeper understanding of the domain, resulting in enhanced knowledge representation.

The authors state that the difference between adaptive and routine expertise is related to different knowledge representations. These differences in representation result in the difference in performance in novel situations.

The authors indicate some items for the learning and working environment which benefit adaptive expertise for the learners:

- activities which stimulate to explore the topic, and thereby also encourages errors,
- supportive supervisors.

For the learner this should result in:

- awareness of the context-specificity of its knowledge
- cognitive and analogical problem solving abilities
- possible higher meta-cognitive skills

Which result in the ability of individuals to develop their own solution strategy.

This can be related to the skills, rules, and knowledge behavior levels described by Rasmussen (1983). Here the routine expertise related to recognizing the signs associated with the task to apply the right rule. While adaptive expertise also adds identifying the symbols to decide which decision is best to reach the end goal. This planning requires knowledge and problem solving abilities related to adaptive expertise.

2-3-3 Past research with unpredictability in training

On a topic which Aerospace Engineering students can probably directly relate to, learning mathematics by practicing problems, Rohrer (2009) shows that mixing problems on different topics increases performance. However, it also states that “mixed review is more demanding than blocked practice, because students cannot assume that every problem is based on the immediately preceding lesson”.

A diverse training helps to enhance the detection of novel stimuli (Gonzalez & Madhavan, 2011). Their research also shows that during the training, the performance is better with less diversity. This makes that in the short run and with a known test, the performance in the test is better if trained with less diversity. However, this is a situation where the test does not relate to reality.

McKinney and Davis (2003) performed a deliberate practice study for crisis decision scenarios with U.S. Air Force fighter pilots. The study shows that for wholly practiced scenarios deliberate practice enhances performance. However, for partially practiced scenarios it concludes that “pilots may need to be trained to explicitly consider higher levels of the cognitive map” to be more aware of their decision making process in selecting their actions.

In a Variability of Practice experiment performed by Huet et al. (2011), 20 novices without prior flight experience practiced the final approach phase. The flight task, performed in

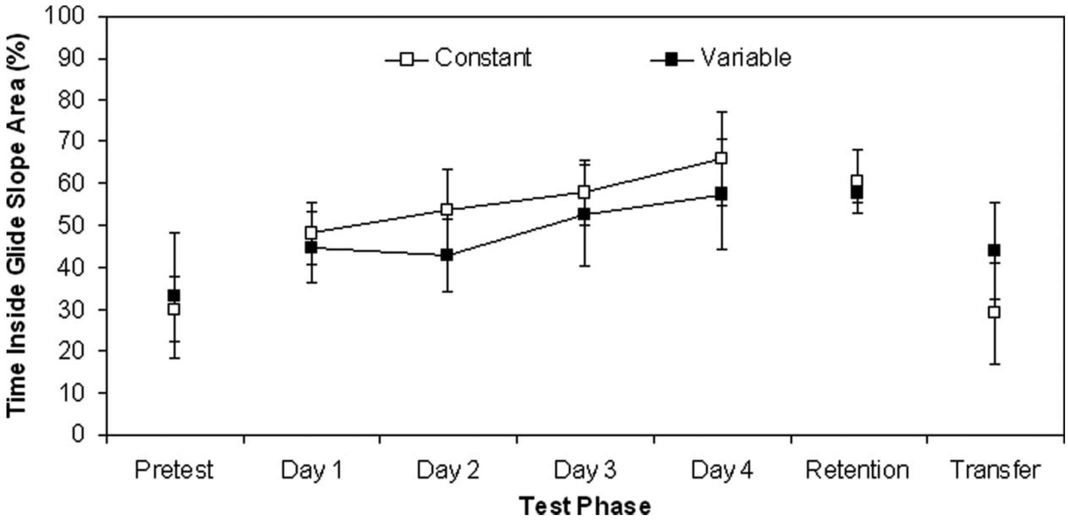

Figure 2-1: Figure with some of the results from the study by Huet et al. (2011). It can be seen that the Variable group has a lower score in the training (day 1 to 4), but shows a smaller drop in the Transfer test compared to the Constant group.

a fixed-base simulator, involved trying to stay within the glide slope area during a visual approach with a Cessna 172. The participants only had to control the altitude of the aircraft.

During the approach, the participant was given concurrent feedback in the form of Precision Approach Path Indicators (PAPIs) when pressing a button on the stick. Terminal feedback was in the form of a 2D side view indicating the aircraft's trajectory as flown during the trial, together with the glide slope area.

The experiment involved two groups of participants, a constant and a variable group. For the variable group, the texture density, runway width, and eye height were changed from trial to trial.

During the training, the performance (percentage of time flown within the glide slope area) of the constant group was better than the variable group. However, in the final test, which was performed without feedback and with unfamiliar condition, the variable group performed better than the constant group, see Figure 2-1.

By providing the variability, participants can determine the usefulness of variables they rely on in their decision making. The focus goes to those variables that give the most reliable information regardless of the variation. While at the same time it becomes clear that some information has to be ignored.

Huet et al. (2011) concludes; "We believe that variability of practice effects are related to the education of attention. The education of attention is hypothesized to proceed faster with variable conditions in part because the usefulness of initially used informational variables is reduced in such conditions."

Chapter 3

Implementation of the non-linear Piper Seneca aircraft model

In this chapter, the available resources to implement the experiment in the SIMONA Research Simulator, using the Delft University Environment for Communication and Activation (DUECA) middleware, are discussed.

Section 3-1 introduces the Piper Seneca and the non-linear model of this aircraft type. This model was already used in an existing DUECA project, which will form the basis of the project for this research, and is described in Section 3-2.

3-1 About the PA-34-220T Seneca III

The aircraft model which will be used for this experiment is of a PA-34-220T Seneca III, a light twin-engined aircraft. This type of general aviation aircraft is often used as a small business aircraft or for twin-engine training. The aircraft has a low-wing monoplane configuration and a retractable landing gear. The cabin can accommodate one pilot and up to 6 passengers. Figure 3-1 shows a Seneca in flight.

The Seneca III was introduced in 1981 as a further development of the Seneca I and II. The major difference are the more powerful engines, two turbo-charged Continental (L)TSIO-360KB 6-cylinder, direct drive, air-cooled piston engines, each delivering 220 hp take-off power and 200 hp continuous power. The engines and propellers are counter-rotating. The aircraft has a wingspan of 38 ft 10.87 in (11.86 m) and a MTOW of 4750 lb (2155 kg).

A twin propeller aircraft with wing-mounted engines has many interesting features. Due to the engine placement, differences in engine power generate large yaw moments around the aircraft's z-axis. The induced flow of each propeller over the wing creates extra lift, which in the case of asymmetric power generates a roll moment. This roll moment is especially strong at low airspeeds. Additionally the aircraft has a noticeable adverse yaw effect.

Figure 3-1: A Piper Seneca. Picture released to the public domain, via Wikimedia Commons.

The basis of the PA34 model used in this experiment originates as an a priori FORTRAN based model written for ATC Flight Simulators in Switzerland (de Muynck & van Hesse, 1990). This non-linear model was translated in a MATLAB Simulink model. An addition made to the model is the separate calculation of the lift from each wing, thereby allowing for the calculation of the resulting roll moment due to the lift difference (Koolstra & Mulder, 2015).

Another difference is the used landing gear model for ground behavior. Instead of the landing gear model from de Muynck and van Hesse (1990), a "broom model" is used whereby the normal and side force on each wheel are combined into one resultant force. The maximum value of this combined force depends on the co-efficient of friction of the runway.

3-2 The current DUECA model

The experiment is to take place in the SIMONA Research Simulator at Delft University of Technology, Faculty of Aerospace Engineering. Therefore, the experiment is implemented using the DUECA middleware in the C++ programming language (see Van Paassen, Stroosma, & Delatour, 2000).

Using Real-Time Workshop version 7.0 (R2007b), C source code is generated from the Simulink model and encapsulated in a DUECA SimulationModule. This old version of Real-Time Workshop is used as the currently used motion-filter depends on this version of Simulink.

Table 3-1: Modules which are part of the Asym1 project.

	Module	Priority	Timing
Input	CitationIncoSelector	admin-priority	slow-timing
	Malfunction	admin-priority	slow-timing
Calculation	FCSAdapter	sim-priority	sim-timing
	PA34	sim-priority	sim-timing
	CvCalculation	sim-priority	cv-timing
	CitationNavigator	sim-priority	display-timing
Output	PA34_engine	admin-priority	display-timing
	B747PFD	admin-priority	display-timing
	CitationLogger	admin-priority	display-timing
Library	B747DisplaysCommonFiles	-	-
	CitationModelInclude	-	-

It is beyond the scope of this project to change the Simulink model, all changes will be made in the encapsulating C++ code.

The DUECA project, used as a basis for this research, is developed by H.J. Koolstra (Herman) for his PhD research and has been used for experiments in SIMONA before (Koolstra, Damveld, & Mulder, 2015; Koolstra & Mulder, 2015). It comes with options to simulate engine failure, engine RPM limitations, decreased control surface effectiveness, rudder hard-over and center of mass changes. The model, named Asym1 on the DUECA server, comes without additional documentation.

The simulation is initially implemented using the DUECA solo-mode on a single computer. Control input is provided using a commercial off-the-shelf joystick. Table 3-1 lists the modules which are part of the Asym1 project and used in the solo-mode. Additional borrowed modules are discussed later. Pseudo modules, used as library holders for including code by other modules, are not discussed.

The Asym1 project was initially based on a Cessna Citation model. The Seneca model was later added, with the option to choose one of these aircraft models for simulation. In the borrowed project the Citation option no longer works, however many remnants of the Citation can still be found in the project in the form of settings, variable names and module names.

Figure 3-2 gives a basic overview of the modules and channels used in the Asym1 project. Boxes indicate modules, with borrowed modules being light grey and own modules dark grey. The ellipses are channels, whereby the solid lines indicate stream channels and the dashed lines event channels. Blue lines indicate write actions to channels, while read actions are visualized using green lines. The red lines indicate there are both read and write actions between the module and channel. This figure is created by checking for read and write tokens in the code, no check is done if data is actually send over the channels.

3-2-1 Input modules

The project contains two input modules for input from the experimenter.

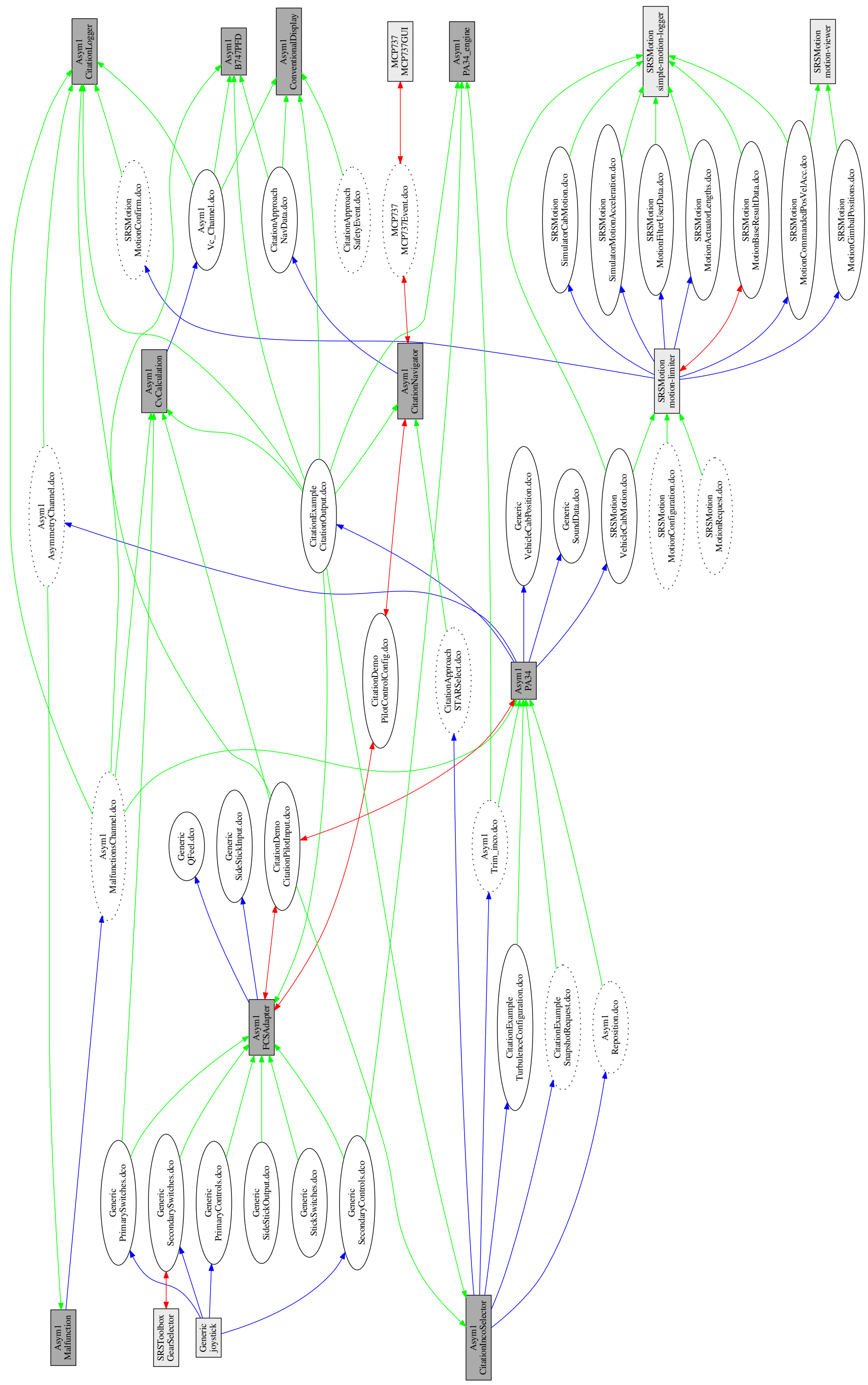

Figure 3-2: Overview of the modules and channels used in the Asym1 project. Borrowed modules are indicated by the light grey boxes, while the dark grey boxes are own modules. The ellipses are channels, whereby the solid lines indicate stream channels and the dashed lines event channels. Blue lines indicate write actions to channels, while read actions are visualized using green lines. The red lines indicate there are both read and write actions between the module and channel.

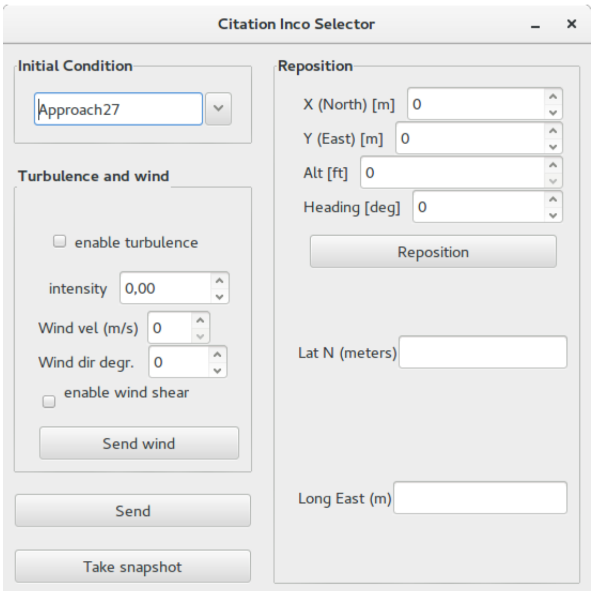

Figure 3-3: GUI for selecting the initial conditions, turbulence and wind, and to (re)position the aircraft. Part of the CitationIncoSelector module.

The first input module is the CitationIncoSelector, used to select the Initial Conditions (INCO), turbulence and wind settings, and to reposition the aircraft. At the same time it displays the current latitude and longitude (flat earth). Figure 3-3 shows the GUI window created by this module.

Using the Reposition option, the position, altitude and heading can be changed independently of the values provided by the INCO. The "Send" button sends both the selected INCO as well as the settings for turbulence and wind provided in the GUI. The turbulence and wind settings can be changed while the simulation is active using the "Send wind" button. This module is based on the CitationIncoSelector as used by multiple Citation projects.

The second input module is used to select malfunctions. Figure 3-4 shows the GUI. When changing a field in the GUI, the module sends out a new event on the channel Malfunctions-Channel. The following text is written to both describe the workings of the different GUI inputs and to better understand the contents of the MalfunctionsChannel.

The box with red solid lines indicates the asymmetry, or mass shift, settings. Asymmetry is added to the model by adding a mass at an x,y,z-location in the standard body reference frame. After pressing the "Send asymmetry" button, both the location of the mass and the mass itself change from the previous situation to the given settings with the specified "rate". This "rate" is the duration in seconds to shift to the new situation and thus not a rate of change. The mass of the aircraft can be changed by selecting a mass while leaving the location in the origin. The module reads from the event channel AsymmetryChannel to display the current asymmetry used in the model.

The asymmetry settings are read by the PA34 module (`PA34_model.cxx`) and implemented into the model over the specified duration. In the current situation the simulation has to be active to change the asymmetry. This includes the removal of any asymmetry.

These items from the MalfunctionsChannel are relevant:

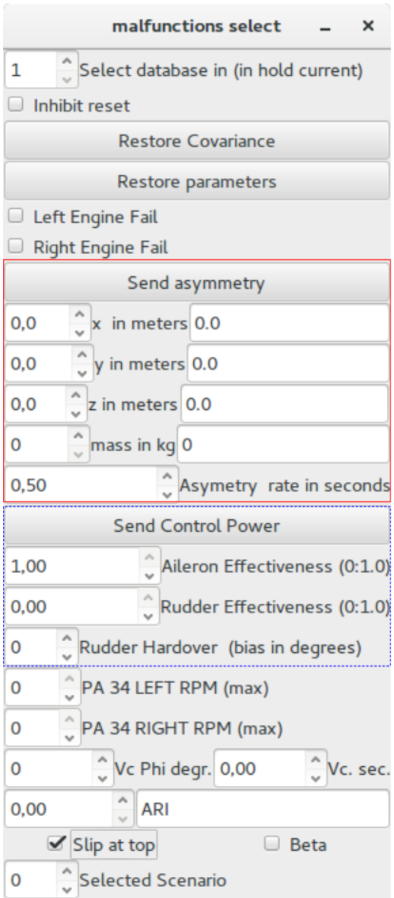

Figure 3-4: GUI for selecting malfunctions. Part of the Malfunction module. Boxes have been added to indicate what is part of the asymmetry selection and what is send when the "Send Control Power" button is pressed.

```
;; button: send asym (true / false button at the moment)
   (bool asym_start)
;; asym location and mass
   (float asym_x)
   (float asym_y)
   (float asym_z)
   (float asym_max)
;; adjustment time duration in seconds (not a rate)
   (float asym_rate)
```

In the case of an event of the MalfunctionsChannel, the PA34 module checks the boolean, if this boolean has changed it reads out the other values and applies the changes. For this it does not matter if the boolean went from true to false or the other way. The check is done in both the simulation states HoldCurrent and Advance.

The box with blue dashed lines indicates what settings are sent when the “Send Control Power” button is pressed. The aileron and rudder effectiveness are set as a number between 0 and 1. The rudder hardover value is the deflection in degrees at which the rudder is fixed. In the Simulink model this has a hardcoded limit of 35 degrees in either direction. If this value is non-zero, the given value for rudder effectiveness is irrelevant. To fix the rudder in the zero deflection position, the rudder effectiveness can be set to 0. A maximum fixed deflection angle of around 5 degrees is said to be doable.

In the same way as for the asymmetry, the boolean is checked for a change. In case of a change in the boolean value the settings are instantly implemented.

```
;; button: send control power
   (bool con_trol)
;; control surface effectiveness - go directly into simulink model
   (float aileron_power)
   (float rudder_power)
;; PA34 model - goes directly into Simulink model
   (float rudder_bias)
```

For the engines two options are provided. The first is to disable engine power completely and the second is to limit the maximum engine RPM. Any changes take immediate effect.

```
;; engine failure --> true = engine fail, false = engine OK
   (bool left_engine)
   (bool right_engine)
;; engine rpm limit
   (float LEFT_RPM)
   (float RIGHT_RPM)
```

The Aileron-Rudder Interconnect (ARI) adds additional rudder output based on aileron input to counteract the adverse yaw effect. A value of 20% (0.20) is given as a good measure if the ARI is set. It has to be determined if the ARI will be used, if it will be a constant, or if it will be varied during a scenario. The PA34 has no ARI.

The check buttons “Slip at top” and “Beta” relate to the output of the Primary Flight Display (PFD). The value for “Selected Scenario” is written directly to the log file (by the module CitationLogger) and can be helpful when analyzing the data.

Finally, the options “Select database in”, “Inhibit reset”, “Restore Covariance”, “Restore parameters” and the two Vc settings all relate to the module CvCalculation.

Due to the way in which the GUI input is handled, it is possible that this module starts sending out events at each timestep. This is due to comparing equality between two floats, and the rounding errors that are associated with floats. Another problem is that the values as displayed at startup can differ from the values that are send out. This is also the case for the InCo display. These problems will be fixed in the new project.

3-2-2 Calculation modules

The project contains a total of four modules that have no direct interaction with the user.

The FCSAdapter is a HardwareModule to link a generic input device with the simulation model. It reads the data coming from the specified input device(s), in the solo case the joystick, converts this, and sends it out as pilot input in a format that can directly be inserted into the model.

A comparison between this copied module and the FCSAdapter module from the Citation-Demo project shows additional calculations for output to the column ("Qfeel"). The required input force on the column and rudder pedals depends on the pressure on the control surface, based on velocity and altitude. This explains the name Qfeel.

The module PA34 is a SimulationModule, an encapsulation of the Simulink model as discussed before. Communications with the Simulink model go via the input vector U, state vector X and output vector Y. These vectors are defined in `CitationModelInclude/StatesOutputs.h`. The input vector contains the following variables:

```
enum input_vec {
  U_de,
  U_da,
  U_dr,
  U_dte,
  U_dta,
  U_dtr,
  U_df,
  U_gear,
  U_pla1,               // throttle position left [0,1]
  U_pla2,
  U_gust_u,             // alleen de eerste drie inputs worden gebruikt in PA34 model
  U_gust_alpha,
  U_gust_beta,
  U_gust_udot,
  U_gust_alphadot,
  U_gust_betadot,
  U_gust_ug_asymm,      // used for left max rpm (malfunction)
  U_gust_ag_asymm,      // used for right max rpm (malfunction)
  U_terr_elev,
  U_asym_x,
  U_asym_y,
  U_asym_z,
  U_asym_mass,
  U_aileron_power,
  U_rudder_power,
  U_rudder_bias,        // alleen met nieuwe versie van Citation model
  U_no_inputs
};
```

The simulated aircraft has a starting mass of 4712 lbs (2137 kg). This consists of an empty mass of 3212 lbs, 6 pax of 170 lbs each (seated per two in the front, center and rear seats) and two times 240 lbs of fuel (left and right wing). The front and rear baggage compartments are empty. The starting mass is 38 lbs (17 kg) under the MTOW of 4750 lbs (2155 kg).

The module CvCalculation contains all code to detect a change in aircraft parameters due to component failures or external damage (Koolstra et al., 2015). In case of a detection, there is an outputs to the PFD. The functionality provided by this module is not used during this experiment, therefor care should be taken to make sure that this module will have no influence on the execution of the experiment or the participants. The code will be slightly altered to either allow for the option to disable its calculations, or to mute all outputs to the pilot. Another option is to remove the module and alter other modules that require input from the CvCalculation module.

The module CitationNavigator handles navigation data and communication with the Mode

Control Panel (MCP). The only difference between this copied module and the CitationNavigator module from CitationDemo (January 2017) is the addition of “101” in:

```
co_token(getId(), NameSet(getEntity(), "CitationOutput", part),101),
```

Documentation says about this value: “For compatibility with older DUECA, not relevant for DUECA 2.0 or later. Used to indicate number of copies reserved in the channel.” Therefor, if no changes are made to this module, it can be borrowed instead.

3-2-3 Output modules

The project contains three output modules, two of which output to displays and one to log.

The PA34_engine module creates a display with engine parameters. This same display also indicates the state of the flaps and landing gear. The display can be seen in Figure 3-5. This module is based on the Citation EngineDisplay module, modified to indicate different parameters for the Seneca’s piston engines instead of the Citation’s jet engines.

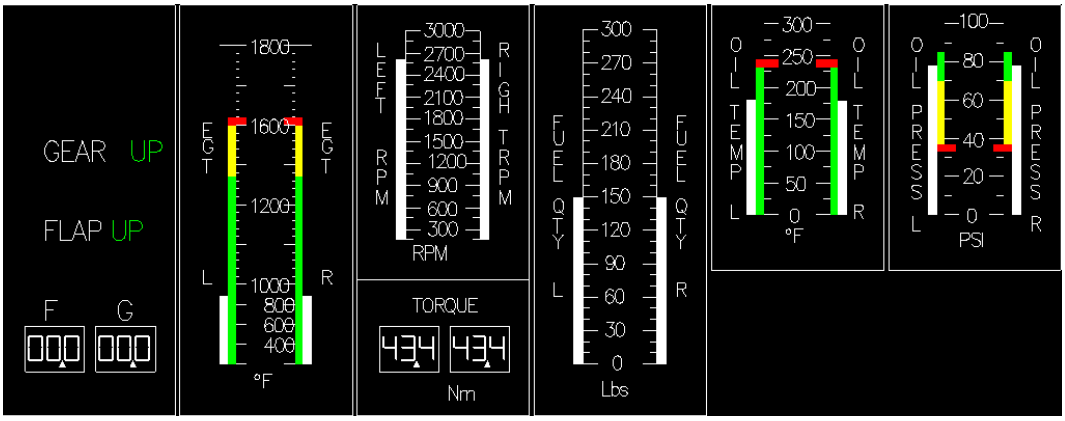

Figure 3-5: Engine Display. Part of the PA34_engine module. The values for fuel quantity and oil temperature are dummy values. The values for exhaust gas temperature and oil pressure are a function of torque and engine RPM, respectively. Engine RPM, torque and the gear and flap setting come directly from the aircraft model.

The indicated engine RPM, torque and the gear and flap setting come directly from the aircraft model. The exhaust gas temperature is a dummy value, calculated based on the torque value. The values displayed for the fuel quantity and oil temperature are hard-coded constants. The indicated oil pressure is also a dummy value and depends on the engine RPM.

The B747PFD module shows a PFD, see Figure 3-6. Modifications include the location of the heading indicator. The heading indicator is moved up, as the control column was blocking the view on the bottom part of this display in case of large deflections. The scenario included an engine failure, while the pilot was instructed to keep a constant heading, requiring large deflections.

The slip indicator can both be placed in the conventional location at the top of the display or in the form of a triangle in the center. The slip can either be based on the sideslip angle β or the force in y-direction as is conventional.

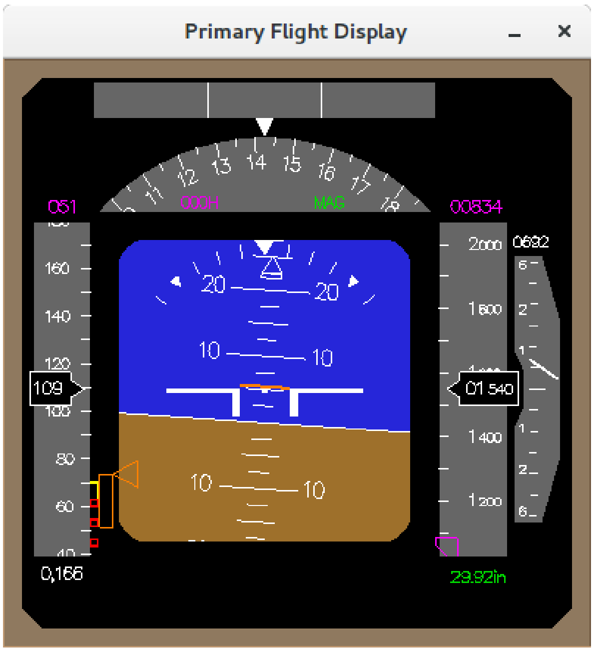

Figure 3-6: Primary Flight Display (PFD). Part of the B747PFD module.

The module CitationLogger logs a total of 75 values to file. Every time the simulation state changes to Advance, a new log file is opened.

3-2-4 Borrowed modules

Table 3-2 lists borrowed modules used by the Asym1 project in solo-mode. Additionally, communications channels are used from various other projects.

The Boeing 737 MCP is part of the SIMONA. Therefor the module MCP737GUI is included to display this hardware in solo-mode. At the moment it does not display any information.

All motion modules borrowed from SRSMotion, and the additional motion filters, are used to calculate and display what the motion would be for the SIMONA cabin.

3-2-5 New DUECA project based on Asym1

Based on the Asym1 project, a new DUECA project named SenecaTraining is set up. This new project copies all Asym1 modules as listed in Table 3-1 and borrows the modules as listed in Table 3-2. In the SenecaTraining project the required changes for this experiment will be made. Any modules from the Asym1 project that are not modified can later be borrowed instead.

Appendices E and F contain an overview of the work performed on the SenecaTraining project in preparation for the experiment, together with items which can be implemented in future versions.

Table 3-2: Borrowed modules used by the Asym1 project in solo-mode.

	Module	Priority	Timing
Input	Generic/joystick	sim-priority	sim-timing
	SRSToolbox/GearSelector	admin-priority	slow-timing
Output	MCP737/MCP737GUI	admin-priority	slow-timing
	SRSMotion/motion-viewer	admin-priority	display-timing
Motion	SRSMotion/motion-limiter	motion-priority	motion-timing
	SRSMotion/simple-motion-logger	admin-priority	motion-timing
Library	SRSMotion/motion-common	-	-
	MotionFiltersRTW50/motion-filters-classical-03r13	-	-
	MotionFiltersRTW50/motion-filters-classical06r13	-	-
	MotionFiltersRTW50/motion-filter-classical-03r13	-	-
	MotionFiltersRTW50/motion-filter-classical-06r13	-	-

3-2-6 Use in the SIMONA

To run the simulation on the SIMONA, a total of nine nodes will be used. These nodes and their modules are listed in Table 3-3.

For more details on the used modules and their configuration, see the dueca.mod file on the srsecs node.

Table 3-3: Modules per node for SRS-mode, as defined in their respective modules.node file. In total there are nine nodes. The modules in italic are only included on the SRS platform, and thus not included on the solo platform.

Node	Module
srsecs	SenecaTraining/CitationIncoSelector
	SenecaTraining/CitationLogger
	SenecaTraining/CitationModelInclude
	SenecaTraining/ECI
	SenecaTraining/Malfunctions
	SenecaTraining/ScoreCalculator
	SenecaTraining/WAVPlayer
	SenecaTraining/WeatherProxy
	CitationApproach/FlapSelector
	MCP737/MCP737GUI
	SRSMotion/motion-viewer
	SRSMotion/simple-motion-logger
	SRSToolbox/GearSelector
srsctrlecat	*CSControlLoading/ControlLoading*
	CSControlLoading/CLConfigurations
	CSControlLoading/CLTools
	CSControlLoading/cl-analyser
	CSControlLoading/IOController
	CSControlLoading/scripts
srsctrl2	*Generic/control-switches*
	Generic/srs-midconsole
srshost	SenecaTraining/CitationModelInclude
	SenecaTraining/FCSAdapter
	SenecaTraining/PA34
	Generic/SideStickController
	MotionFiltersRTW70/motion-filter-classical-16
	MotionFiltersRTW70/motion-filter-tuner
	SRSMotion/motion-common
	SRSMotion/motion-limiter
srsefis1	SenecaTraining/B747DisplaysCommonFiles
	SenecaTraining/B747PFD
	SenecaTraining/CitationModelInclude
	SenecaTraining/CitationNavigator
	Generic/multi-stick
	MCP737/MCP737Proxy
srsefis2	SenecaTraining/CitationModelInclude
	SenecaTraining/PA34_engine
srsig1, -2 & -3	CitationDemo/FGVisual
	HapticFlightEnvelopeProtectionTestBench/FGWeather

Chapter 4

Defining and implementing experiment scenarios

After discussing the workings of the model in the previous chapter, this chapter discusses possible scenarios for familiarization, training and testing in this experiment. Before scenarios can be defined, Section 4-1 lists requirements that each scenario has to comply to for use in this experiment. Section 4-2 lists what variables can be defined and varied to make a scenario. Section 4-3 defines options for familiarization and training, with Section 4-4 adding scenarios for testing. How this is implemented in DUECA is briefly discussed in Section 4-5.

4-1 Requirements for scenarios

In a simulated environment, it is possible to safely perform many aircraft failures. However, it is easy to overwhelm the pilot and to make the aircraft crash in endless different ways. However, this is not the idea of this experiment. To make a scenario usable, it has to comply with the following requirements:

- *Clear goal.* A clear goal for the pilot is important to keep the pilot focused (and busy) and second this should prevent that each pilot deals with the situation in a different way, making comparisons between pilots and between groups impossible.
- *Doable.* Performing the scenario with a good outcome is possible. This provides positive training to the pilot and should provide more motivation to perform the scenarios well.
- *Realistic.* While a simulation environment given the option to poke around and try again and again until one succeeds, this brings the pilot in a "simulation mindset". Not only does this give the pilot a false sense of their abilities, it is also not useful in real-life situations where the first time has to be right.

- *Start in a stable situation.* Starting in a stable situation gives the pilot time to get into the situation while the simulation is already running. The event happens after some time in the scenario. This way the pilot does not have to brace and prepare before the simulation is started.

All the developed scenarios will be tested in the SIMONA to verify they can give the participants a sufficient level of training. It is also important that the scenarios can be performed for the duration of the experiment without too much strain on the participants. If during testing it turns out a scenario either requires too little or too much from the pilot, additional elements can either be added or the task can be simplified. The goal is to make a challenging and not a hopeless situation.

4-2 Options for creating experiment scenarios

Each scenario either starts on the runway or with an undamaged aircraft in straight and level flight. If the aircraft starts on the ground, it is possible to start with a malfunction which will become apparent on take-off. The problem should not be obvious during taxiing, as in this case the pilot might abort the scenario immediately and not even attempt to take off.

For each scenario, the following starting conditions have to be defined:

- Altitude; upto 12,000 ft.
- Airspeed; between 80 and 180 KTAS.
- Attitude; straight and level flight.
- Latitude, longitude and heading. Important for scenarios involving landing on a runway or when starting on the ground.
- Turbulence and wind conditions.
- Additional variables, which can be added to the project. Options include visibility and clouds.

Some of these variables can be varied between runs of the same scenario. For example the same scenario can be performed at 2,000 and at 10,000 ft, or under smooth and turbulent flying conditions.

The landing gear will either be up or down, depending if the start is in the air or on the ground. It is possible to start in the air with the gear down, however the maximum speed for flying with the gear down has to be taken into account. The same goes for the flaps.

The atmospheric conditions in the model are always according to the International Standard Atmosphere (ISA). Therefore the chosen altitude directly influences the atmospheric conditions acting on the aircraft. The ground is always at zero elevation, meaning the atmospheric conditions on the runway are constant. If required this can be modified by adding a delta input on the altitude or air pressure in the atmospheric model, which calculates air density ρ and temperature T based on the altitude.

It is possible to make the environment conditions (wind, wind shear, and turbulence) change slowly during the scenario. However, taking into account the expected duration of a scenario this might make the scenario too complex for use in this experiment.

At a specified time into the scenario, an event occurs. This event can be any of the malfunctions included in the model, but if required additional events can be added to the model. The malfunctions have been discussed in Section 3-2-1, including their implementation in the model. To summarize:

- Asymmetry due to a mass shift; Set arm (x, y and z), mass and adjustment time.
- Aileron and rudder effectiveness; Set effectiveness (none to full effectiveness; value between 0 and 1).
- Rudder hardover; Set fixed deflection angle for the rudder (nonzero value between -15 and 15 degrees).
- Engines, complete failure or limited RPM; Set boolean or maximum RPM (value upto 2800 RPM).

Any combination of these failures can be used in parallel, with the exception of the rudder hardover which overrules the rudder effectiveness setting. In case of an engine failure, the engine will continue to windmill (drag comparable to a feathered prop). In this case the maximum RPM can still be set.

In the case of an undamaged aircraft, there is no asymmetry, aileron and rudder are fully effective and both engines are running with a maximum of 2800 RPM.

4-3 Creating experiment scenarios for training

The training scenarios should provide some preparation for the final testing scenarios, while not be too specific to prevent the “training to the test”. Ideas for scenarios for pre-test and training:

- Mass shift to the rear, making the aircraft to pitch up.
- Engine failure on approach
- Turn with a rudder hardover
- Asymmetry with one wing heavy
- Take-off with limited aileron control

The mass shift can either be a sudden change, or a slow change to increase the level of surprise.

Further options for use in scenarios, requiring additions to the simulation, include

- Display offset on the airspeed and/or altitude

- Loud noises and bangs
- Reduced power available, but not a full engine failure
- Variable duration of changes in the power available
- Reduced visibility or other changes in the outside visuals (FlightGear)
- Elevator malfunctions

4-4 Creating experiment scenarios for testing

Following the training runs, a more realistic and elaborate scenario is performed in a different context, whereby the participants are given no information on what will happen. The scenarios are expected to take the full effort from the participant, but should not result in an overload.

Ideas for these scenarios include and engine failure in initial climb (Section 4-4-1), a combined mass shift and engine failure (Section 4-4-2) and a control performance test without failure (Section 4-4-3). Note that these are the scenarios the process of scenario selection started with, the final scenarios for use in the experiment are presented in the following section.

4-4-1 Scenario A: Engine failure in initial climb

Take-off according to a pre-defined procedure discussed during the briefing. Pilots can be given weather information, etc, during the briefing. While irrelevant, it can add to the load experienced during the scenario.

The simulation starts on runway. The pilot is instructed to take-off, climb to 2000 feet with specified ascent rate and 90 knots airspeed, at this altitude follow a left or right hand circuit (which direction is given during climb), the flight will end with an approach and landing.

However; shortly after take-off one engine will fail. The pilot has to compensate for the moments resulting from the thrust asymmetry, while still maintaining the climb.

The one engine inoperative situation gives both a yaw moment and a roll moment. The yam moment is the result from the thrust asymmetry on the planes y-axis and has to be compensated with the rudder. The rudder effectiveness however depends on the airspeed. The roll moment results from the induced flow over the wing from the still running engine and propeller, generating additional lift on one wing resulting in asymmetric lift.

This scenario is based on the 1996 Lockheed C-130H Hercules crash at Eindhoven, The Netherlands. In this accident bird ingestion caused power loss in the two left engines, resulting in the aircraft becoming uncontrollable at a very low altitude.

4-4-2 Scenario B: Leak in fuel tank

A leak in the fuel tank of one wing due to an impact with an external object. This situation starts with a loud bang and an increase in turbulence. This is followed by a mass drop on one wing, followed by the loss of the engine on this wing due to fuel starvation.

This scenario requires the indication of the decreasing fuel quantity in the display. If needed the difficulty of this scenario can be increased by including a decreased aileron performance due to the damaged wing.

In this scenario the mass drop and the engine out create opposite yaw moments. This slowly-evolving surprise scenario gives time for sense-making.

4-4-3 Scenario C: Challenge

As a final test, a challenge can be performed. The pilot is told to climb as fast as possible to 1000 ft with an airspeed of 90 knots and zero side-slip angle beta. Something will happen on the way to surprise/startle the pilot. Furthermore no malfunction is included to add to the confusion. Options for the event are a sudden temporary increase in turbulence or a loud sound. This is mainly a focus test where the pilot has to concentrate on the task and no other actions have to be taken.

4-5 Implementation of scenarios into simulation environment

Having defined some scenarios, in this section it is discuss how the scenarios will be included in the model for use during the experiment.

To make sure all participants are presented with equal training and testing scenarios, for each scenario the defined initial condition and occurring events will be saved in a configuration file. This file can be selected and loaded in the DUECA simulation, in a similar way as the INCO can be selected. This also reduces the workload of the experimenter and prevents that events are either forgotten or started at different times.

For this purpose a new module will be added to the project, providing a GUI to select the scenario. This Experiment Control Interface (ECI) module reads the configuration file, sets the initial conditions and sends out its own events over the MalfunctionsChannel and TurbulenceConfiguration event channels. In sending malfunction events it works comparable to the Malfunction module of the Asym1 project, and with modifications both can be used in parallel for testing purposes.

The ECI is required to provide the following functionality:

- Select one of the scenarios
- Read the scenario from file
- Send INCO
- Display (some) details about the selected scenario
- Display (some) of the current values
- Send malfunction events
- Display a countdown to the time of sending the next event

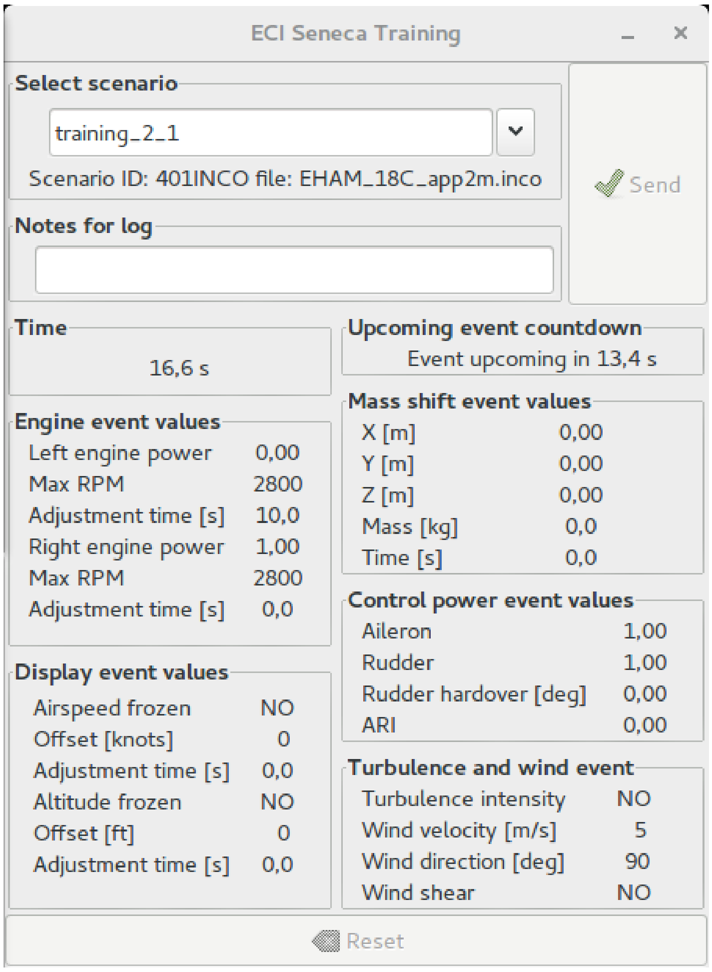

Figure 4-1: Experiment control interface GUI. At the top a scenario file can be loaded. The items in the lower half of the GUI indicate the currently loaded values, ready to be send out when the module is triggered.

The scenarios are defined in a plain text file. It defines the INCO, the details on the event(s) and the time at which this event happens. Using this method it will be easy to modify an existing scenario and to include additional scenarios into the simulation. The scenario file can be modified at any time without the need to restart, thereby allowing for quick iterations during testing.

Figure 4-1 shows the ECI GUI. At the top available scenario files can be selected from a (dynamically generated) drop-down list. The displayed event values are the settings loaded from the selected scenario file, which will be send at the indicated time. The buttons are deactivated when the simulation is running to prevent unintentional input when accidentally clicking the button.

How scenarios can be defined for use in the simulation is described in a `README` file included with the project. This file is included in Appendix D.

Chapter 5

Experiment Plan

This chapter brings together the research proposal in Chapter 1 and the literature in Chapter 2, to perform a human in the loop experiment based on the model discussed in Chapter 3 and scenario possibilities described in Chapter 4.

The experiment is performed using the SIMONA Research Simulator and aims to find the effect of two different training methods on pilot performance. Section 5-1 lists the hypotheses of the experiment. The experiment set-up is discussed in Section 5-2.

The predictable training method will be called *Training 1* and the unpredictable training will be called *Training 2*. For each training method, a different group of participants is required, making for a between-subjects design. The group subjected to Training 1 is called *Group 1*, the other group is called *Group 2*. Details on the participants required is discussed in Section 5-3.

The experiment procedure, including participant briefing, tasks in the simulator and the debrief afterwards, is discussed in Section 5-4. Also including the scenarios used for training and testing and the order in which they are presented.

5-1 Hypotheses

The hypotheses for the experiment outcome are:

1. During training the pilots in Group 1 will initially perform the task better than Group 2. As the scenario is more predictable, they have more mental resources available for performing their tasks in the scenario.
2. During training the pilots in Group 2 will have a higher mental workload than those in Group 1.
3. In the final test the pilots that received Training 2 will perform better than the pilots that received Training 1. While the test scenario is new for both groups, Group 2 is expected to have a broader understanding of the airplane dynamics and has better learned to analyze and identify the problem.

5-2 Experiment set-up

5-2-1 Control variables

All participants take place in the right seat of the SIMONA Research Simulator. Use will be made of the motion system for all scenarios. The outside visuals are powered by FlightGear, providing PAPIs to indicate the approach path. The wind socks at each end of the runway indicate the correct wind direction and velocity used in the scenario.

Pilot control input inside the SIMONA is done by using a new steering column currently under development. In case this steering column is not ready in time, the already installed side stick for the right seat is used. The currently installed rudder pedals are used, including control loading. On the Boeing 777 mid-console, the throttles for left and right engine and the flap selector are used. The gear is operated using the gear handle in the center of the cockpit, in between the displays.

The instruments already in the model will be displayed on the screens inside the simulator cockpit, whereby the engine data is displayed on the navigational display.

The inside of the SIMONA will not be modified to resemble the Seneca cockpit. As this experiment is not a training program for this particular aircraft, the SIMONA cockpit with the above mentioned control inputs and displays will suffice.

Additionally, engine sound is provided over the headset as background noise. The pitch of the sound is scaled to the engine RPM and the volume depends on the engine torque. While this is calculated for the two engines separately, the current audio system with the headset is mono.

5-2-2 Independent variables

In this experiment there are two different training schemes. Training 1, given to Group 1, is predictable while Training 2, given to group 2, is unpredictable.

There are a total of 14 training runs, divided over three topics. Following the training, all participants receive the same testing scenarios.

The differences in predictability for the two training schemes are based on Section 2-3. They are related to:

- Instruction - In Training 1, the scenario details and instructions are given before the first run. This includes the task to be performed, the wind condition, the malfunction and how to handle the malfunction. For Training 2 the first run of a training scenario is done with the same instructions for the task and wind condition, but only with the info that a malfunction will happen to which they have to respond appropriately. After the first run the participant is informed on the details of the scenario. The idea is that with more info before the training, the focus is on the task and less on the situation. While instructions are given at different moments, participants in both groups receive the same information.
- Order - For Training 2 the scenarios are mixed, with only two consecutive runs about the same topic. Group 1 receives each topic grouped and in order.

- Variation - For Training 2 each run is different, while the same task is performed it is always under different conditions. Only one of these conditions is presented in Training 1. The variations are in wind velocity and direction, turbulence, visibility, instructed velocity and the side, timing and strength of the malfunction.

Together these differences make that one group can focus on the task and perform best, while the other group gets a better idea of the aircraft in different situations. Both groups receive equal attention during the experiment, performing the same number of runs and spending similar[1] time in training.

5-2-3 Dependent variables

The dependent variables have to give an indication of pilot performance. Therefor the measures used in earlier experiment, some of which were discussed in Chapter 2, were analyzed.

Due to the difference between scenarios, the dependent variables differ per scenario. For the pre- and post-test, used measures can be centerline deviation and aileron input in approach, the landing position and touchdown rate. For each training scenario, task performance gives a measure of pilot control performance. Another measure is the response time after the malfunction is introduced, based on control inputs or call-out. These measures can also be used for the test scenarios, together with the maximum airspeed, maximum rate of descent, load factor, or total altitude loss. For the two test scenario a measure also is if the objective was achieved (yes/no), defined as noticing the erroneous airspeed indicator and a successful landing versus loss of control, respectively.

Measure of the heart-rate or pulse and skin conductance is not used, as in earlier experiments by Annemarie Landman these measures did not give significant results.

5-3 Participants

Because of the use of two training schemes, a between-subjects experiment setup is required. For this experiment it is expected to have between 16 and 20 participants, which gives 8 to 10 participants in each group. This is based on the amount of data required to draw conclusions from the experiment outcome and the (simulator) time available to perform the experiment.

5-3-1 Criteria for participants

The participants will be licensed commercial jet pilots without extensive experience on multi-engine propeller aircraft. The use of licensed pilots makes that all participants have flying experience, and a minimal level of airmanship can be expected. Additionally, the use of commercial pilots allows us better to draw references to training of commercial pilots.

Annemarie Landman (supervisor) has a list of potential participants, which she also used for a previous experiment.

[1]Note that the exact duration of each run depends on the actions taken by the pilot, therefor each participant will spend a different time in control of the aircraft.

5-3-2 Distribution over the two groups

The two groups with equal number of participants will have to be as equivalent as possible using sampling of the available participants. The participants can be assigned to a group based on either their experience as indicated before the experiment, or their performance during a test at the start of the experiment. By using the second method the groups can be made more equivalent when it comes to manual flying performance. A drawback of the second method is that the groups are filled one by one as each participant performs the experiment, and only in the end can it be determined if the groups were relatively equivalent.

The participant does not know to which group he or she is assigned and what the difference is between the groups.

5-4 Experiment procedure

This section describes the different steps for the participant before, during and after the experiment. Figure 5-1 gives a quick overview of the different steps in the simulator.

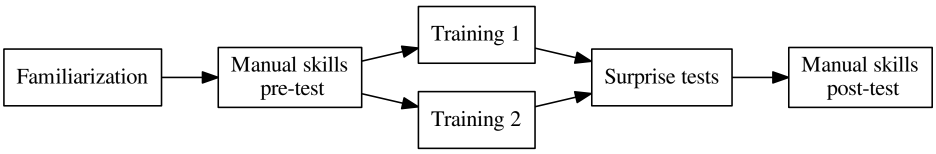

Figure 5-1: Overview of the different steps performed in the simulator, showing the similarities and difference between the two groups.

In total the experiment is expected to take about two hours. This includes a briefing before the experiment, all experiment tasks, the post-experiment questionnaire, and time to discuss afterwards. The time in the simulator will be 1 hour 15 minutes.

5-4-1 Briefing

All participants will get an introduction to the experiment right before the experiment. They are told they are participating in a training methods experiment with scenarios containing technical malfunctions, influencing the controllability of the aircraft. The briefing further includes information on the used aircraft model, available control inputs, and details on the familiarization scenarios. Pilots are requested to perform the task given, and continue doing so after they notice a malfunction. This to be able to compare between participants. Participants are requested to give an immediate call-out when they notice something with the aircraft, together with what they think is the problem.

Using a paper form, the participating pilots are asked for their age, their experience (aircraft type and hours), the years since finishing their airline pilot training and their current function.

Before the experiment the rights of the participant will be given to them both in writing and verbally. See Appendix A for the consent form. When taking their seat in the SIMONA they will receive the standard safety briefing.

After taking place in the right hand seat, they are shown the controls (side stick with pitch trim, rudder pedals, flap selector, throttles, gear handle) and the displays.

During the experiment, the participant will wear a headset for direct verbal communication between the participant and the experimenter. The participant has an open mike and there is no protocol for communications. All scenarios will be flown with manual control, no use will be made of an autopilot. Only the participant takes place in the SIMONA, there is no co-pilot or assistant present. However, questions can be asked at all times. The engine sound provided over the headset shall not be too loud to obstruct voice communications.

5-4-2 Familiarization

At the start of the experiment, two familiarization runs are performed to let the participants familiarize with the aircraft model and the environment.

Both runs consist of a left-hand circuit at 1000 ft and a speed of 130 kts. The take-off and landing is performed at Schiphol runway 18C. The first familiarization flight is done in a nominal situation without wind. The second familiarization flight contains moderate crosswind.

During the downwind leg participants are asked to try out the controls.

5-4-3 Pre- and post-test on manual skills

The pre-test consists of an approach and landing without rudder, under moderate crosswind conditions. The test is used to obtain a baseline performance measurement for the manual flying skills of the participants. The pilots are scored for their performance and based on that allocated to one of the two groups. The post-test, the last scenario flows, is equal to the pre-test and used to compare manual flying performance before and after the training.

5-4-4 Training

There are a total of 14 training runs, divided over three main training scenarios with each a different malfunction on the aircraft.

The first scenario starts on the runway, at the 3000 ft mark to reduce the length of runway available. The pilot is instructed to take-off and fly the circuit as done during the familiarization. During the take-off a single engine failure occurs, as given in Table 5-1. All take-offs are performed under light crosswind conditions.

The second and third scenario both start in approach, at about 2 minutes flight time straight in front of the runway. While approaching the runway a malfunction happens, see Tables 5-2 and 5-3 for exact details. With this malfunction the pilot has to perform a fly-by over the runway at 100ft and 85 kts, while staying on the centerline. Additionally, Group 2 is instructed to increase their speed over the second half of the runway. Variation 3 and 4 also contain reduced visibility of 9000 meters.

Participants in the repetition group perform the first scenario from Table 5-1 three times, followed by three times the second scenario. This is followed by four times the first scenario from Table 5-2 and four times the first scenario from Table 5-3.

Table 5-1: Variations for the first training topic: A single engine failure on take-off

Variation	Details	ID
1	When the gear comes up, left engine loses all power	301
2	When reaching 65 knots, right engine drops to max 1500 RPM	302
3	At rotate, right engine loses all power	303
4	When reaching 270 ft, right engine loses all power	304
5	When the gear is halfway up, left engine loses all power	305
6	When reaching 310 ft, RPM drop and power loss on right engine	306

Table 5-2: Variations for the second training topic: Approach and fly-by with a fixed rudder deflection. Wind speed is 7 m/s.

Variation	Rudder deflection	Wind direction	ID
1	15 degrees after 20 seconds	270°	411
2	20 degrees after 50 seconds	180°	412
3	25 degrees after 50 seconds	90°	413
4	10 degrees after 30 seconds	270°	414

Participants in the unpredictable group perform all scenarios given in the three tables, but they only see each scenario once. They start with the first two scenarios from Table 5-1. This is followed by the first two scenarios from the next table, continuing until all scenarios have been performed.

After performing two training runs the participant fills in two NASA TLX mental demand scale, one scale for each run.

5-4-5 Test with surprise

For the test there are two scenarios containing a take-off and a landing, both performed at Lelystad Airport (EHLE) runway 05. The pilot is instructed to again fly a left-handed circuit at 1000 ft and to respond appropriately to what may happen.

The first is a distraction scenario, whereby shortly after rotate the indicated airspeed starts to drop with one knot/second. This is purely an offset between the actual and the indicated airspeed. Apart from the increasing negative offset on the indicated airspeed in the PFD, there are no other malfunction on the aircraft.

Table 5-3: Variations for the third training topic: Approach and fly-by with a single engine failure. Wind speed is 5 m/s.

Variation	Engine failure	Wind direction	ID
1	Left engine failure after 20 seconds	270°	421
2	Right engine failure after 40 seconds	270°	422
3	Left engine failure after 30 seconds	90°	423
4	Right engine failure after 50 seconds	90°	424

The second scenario contains a partially trained malfunction, however this time it manifests itself differently from the training scenarios. When the aircraft reaches an airspeed of 55 knots, the right engine power is reduced to 40% over a period of 20 seconds. When reaching an altitude of 490 ft the left engine has a hick-up, consisting of a power reduction to 50% (reduced over 4 seconds, and going back to nominal 2 seconds later). This is done to force the pilot to make use of both engine, especially in the case where the right throttle is already fully pulled back. When exiting the turn going to the downwind leg, a second malfunction is introduced. While the pilot applies rudder to compensate the yaw moment due to the failed engine, the rudder effectiveness is decreased to 20%.

5-4-6 Post-experiment questionnaire and debrief

After leaving the simulator the participants fill out a questionnaire about the two test scenarios with surprise. The questionnaire is split in three parts, each having the same questions. The first part focuses on the take-off with reduced power and engine hickup, until the rudder effectiveness reduction. The second part focuses on the rudder reduction and the performed landing. The third part focuses on the circuit with the false airspeed indication. The questionnaire ends with some questions about the given training. The post-experiment questionnaire can be found in Appendix B.

The questionnaire contains the NASA Lask Load Index (TLX) (except Temporal Demand), a VAS Anxiety Scale and questions about surprise for each of the three parts. For the training the Intrinsic Motivation Inventory (IMI) is used.

The goal of the questionnaire is to get an indication (subjective) of the pilot workload, level of surprise and thinking when presented with scenarios, and to verify that the scenarios are indeed surprising and challenging to the participants.

When the questionnaire is finished, the participants are informed about the purpose of the experiment. Questions can be asked and feedback is given when requested.

Chapter 6

Conclusion

In this preliminary report a research has been proposed to find if there is a benefit in training with unpredictability to better prepare pilots for surprise situations that can occur during operations. An attempt was made to list the current shortcomings in current mandated pilot training, how unpredictability can be added to a training and what benefits could be expected. The main research question was:

What is the effect of unpredictability in training on pilot performance in a surprise situation?

This question was split into several sub-questions, some of which have been answered in this report.

1. The current training practices for unexpected situations given to airline pilots have to comply with the regulations. As the time available for simulator training is limited, variations have been brought to a minimum with a focus on predetermined responses. This takes the element of surprise out of the training, as essential part of the training to prepare the pilots for the range of situations that can occur in normal operations.

2. Startle and stress, which might result from a surprise situation, have a negative effect on pilot performance. For highly practiced tasks performance is largely automated. However, when faced with a situation outside of the known realm, the automated response is not suitable. This situation requires mental effort, drawing on the pilots attention, cognition, memory, and working memory performance.

3. The following methods have been found to make the training less predictable for the pilot:

   - Constructivist learning (discovery-based instruction and enhanced-discovery), whereby the pilot is presented with the scenario and limited instructions. After performing the scenario once, additional instructions are given before the scenario is repeated. This way both groups receive the same instructions.

- Context interference, whereby the order of scenarios is mixed. This way the pilot cannot simply assume that the following problem is based on the immediately preceding scenario. The pilot is required to identify the situation for each run.
- Variability, whereby each repetition of the same scenario is slightly different. By providing the variability, learners can determine the usefulness of variables they rely on in their decision making and focus on those variables that give the most reliable information regardless of the variation.

4. The Piper Seneca model and the implementation on the SIMONA simulator was described. The model already comes with possibilities to simulate engine failure, engine RPM limitations, decreased control surface effectiveness, rudder hard-over and center of mass changes.

To answer the main question an experiment will be performed using the SIMONA Research Simulator at Delft University of Technology. For the experiment to answer the research question, some important elements have to be right:

- The difference between the two trainings provided has to be different enough to see a difference in the tests, while not too different to invalidate the results.
- Over the limited time available for training the scenarios have to prepare the participants for the tests, while not taking away the surprise for one or both groups.
- The scenarios, especially the testing scenarios, have to provide the correct difficulty level to see a possible difference between participants and between groups. If it is too simple pilots will easily achieve the objective, while if it is too difficult it might be impossible to draw conclusions.
- The participants have to indicate that the situations presented in the surprise tests were indeed surprising.

Next to this there are (technical) risks associated with performing this experiments, related to the model, the SIMONA and the use of human participants:

- The Piper Seneca model has, unlike the Citation model, not been extensively used for experiments before. Therefore it is expected that considerable coding work is required to reliably use the software. To limit the work, the decision was made to make no changes to the Simulink model.
- The available timeslots on the SIMONA are limited, especially during the time the experiment is expected to be performed. Next to this the right configuration inside the cockpit is required for the duration of testing, scenario development and performing the experiment.
- To checkout, implement and test the project on the SIMONA the availability of specific staff members is required.

- A breakdown can (partially) put the simulator out of use for a period of time ranging from a day to over a month. As this project requires the motion system, outside visuals, displays and multiple control input devices, a problem with one of these elements can delay the experiment.
- Making use of commercial pilots instead of students has a benefit, but also brings extra challenges in participant availability.
- The uniqueness of each scenario and the extend of freedom for the participants makes analysis of the data more difficult.

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Part III

Appendices

Appendix A

Informed consent form

The following page contains the consent form given to the participants during the briefing, prior to the experiment.

Toestemmingsverklaringformulier (informed consent)

P. (Peter) van Oorschot en H.M. (Annemarie) Landman

Titel onderzoek: Training and piloting skills
Verantwoordelijke onderzoeker: René van Paassen

In te vullen door de deelnemer

Ik verklaar op een voor mij duidelijke wijze te zijn ingelicht over de aard, methode, doel en de risico's en belasting van het onderzoek. Ik weet dat de gegevens en resultaten van het onderzoek alleen anoniem en vertrouwelijk aan derden bekend gemaakt zullen worden. Mijn vragen zijn naar tevredenheid beantwoord.

Ik stem geheel vrijwillig in met deelname aan dit onderzoek. Ik behoud me daarbij het recht voor om op elk moment zonder opgaaf van redenen mijn deelname aan dit onderzoek te beëindigen.

Ik begrijp dat film-, foto, en videomateriaal of bewerking daarvan uitsluitend voor wetenschappelijke analyse zal worden gebruikt. In aanvulling daarop ga ik:

• wel / niet* akkoord met het gebruik van foto- en videomateriaal voor presentaties door de onderzoekers. *doorhalen wat niet van toepassing is

Naam deelnemer: ______________________________

Datum: ________________ Handtekening deelnemer: ________________

In te vullen door de uitvoerende onderzoeker

Ik heb een mondelinge en schriftelijke toelichting gegeven op het onderzoek. Ik zal resterende vragen over het onderzoek naar vermogen beantwoorden. De deelnemer zal van een eventuele voortijdige beëindiging van deelname aan dit onderzoek geen nadelige gevolgen ondervinden.

Naam onderzoeker: ______________________________

Datum: ________________ Handtekening onderzoeker: ________________

Appendix B

Post-experiment questionnaire

This appendix contains the questionnaire given to the participants after the experiment.

Post-experiment vragenlijst

Hartelijk dank voor uw deelname aan het experiment. De volgende vragenlijst dient om inzicht te krijgen in uw beleving van de taken. Vul de vragen a.u.b. zorgvuldig in. Veel vragen zijn in het Engels, omdat de schalen niet zomaar vertaald mogen worden. Uw ingevulde gegevens worden vertrouwelijk behandeld en anoniem verwerkt.
Het experiment bestond uit de volgende onderdelen:

> **Scenario 1**: Een landing zonder rudder (start in approach).
>
> **Training:** Zes maal een engine failure tijdens take-off en acht fly-by's over de baan.
>
> **Scenario 2**: Een circuit met een fout in de snelheidsindicator.
>
> **Scenario 3**: Een circuit met daarin eerst een engine failure bij take-off en vervolgens (op downwind) een beschadiging van het rudder.
>
> **Scenario 4**: Een landing zonder rudder (identiek aan scenario 1).

De volgende vragen gaan over het reageren op, en vliegen met, de engine failure bij take-off in **Scenario 3**, tot aan het moment dat ook het rudder werd beschadigd in dat circuit. U dient de rudder beschadiging dus niet mee te nemen in uw antwoorden.

Mental Demand How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

Very low Very high

Physical Demand How much physical activity was required? Was the task easy or demanding, slack or strenuous?

Very low Very high

Frustration Level How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Very low Very high

Performance How successful were you in performing the task? How satisfied were you with your performance?

Perfect ——————————————————— Failure

Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

Very low ——————————————————— Very high

Omcirkel a.u.b. steeds één antwoord om de volgende vragen te beantwoorden:

How surprised were you when you discovered the engine failure?

Not at all	Slightly	Moderately	Very	Extremely

How well did the engine failure fit into your "mental picture" of the upcoming events?

Very poorly	Slightly	Moderately	Well	Very well

How difficult was it to understand what had happened?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How difficult was it to think of the potential consequences of the engine failure for the rest of the flight?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How did you have to change your plans for the rest of the flight?

Very little	Somewhat	Moderately	Seriously	Very seriously

How startled or shocked were you when you discovered the engine failure?

Not at all	Slightly	Moderately	Very	Extremely

How well did the training prepare you to deal with the engine failure?

Very poorly	Poorly	Moderately	Well	Very well

How well did your previous experience as a pilot prepare you to deal with the engine failure?

Very poorly	Poorly	Moderately	Well	Very well

How much tension or anxiety did you feel following the engine failure up until the subsequent rudder failure? (please place a cross on the line).

Extremely little ——————————————— Maximum

Kunt u omschrijven wat uw gedachten of plannen waren toen u de engine failure ontdekte?

....

....

....

De volgende vragen gaan over de rudder beschadiging op downwind in **Scenario 3** (het circuit met ook de engine failure) en over de landing die daarop volgde.

Mental Demand How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

Very low ——————————————— Very high

Physical Demand How much physical activity was required? Was the task easy or demanding, slack or strenuous?

Very low ——————————————— Very high

Frustration Level How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Very low — Very high

Performance How successful were you in performing the task? How satisfied were you with your performance?

Perfect — Failure

Effort How hard did you have to work (mentally and physically) to accomplish your level of performance?

Very low — Very high

Omcirkel a.u.b. steeds één antwoord om de volgende vragen te beantwoorden:

How surprised were you when you discovered the rudder failure?

Not at all	Slightly	Moderately	Very	Extremely

How well did the rudder failure fit into your "mental picture" of the upcoming events?

Very poorly	Slightly	Moderately	Well	Very well

How difficult was it to understand what had happened?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How difficult was it to think of the potential consequences of the rudder failure for the rest of the flight?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How did you have to change your plans for the rest of the flight?

Very little	Somewhat	Moderately	Seriously	Very seriously

How startled or shocked were you when you discovered the rudder failure?

Not at all	Slightly	Moderately	Very	Extremely

How well did the training prepare you to deal with the rudder failure?

Very poorly	Poorly	Moderately	Well	Very well

How well did your previous experience as a pilot prepare you to deal with the rudder failure?

Very poorly	Poorly	Moderately	Well	Very well

How much tension or anxiety did you feel during the subsequent landing?

Extremely little ◆————————————◆ Maximum

Kunt u omschrijven wat uw gedachten of plannen waren toen u de rudder beschadiging ontdekte?

....

....

....

....

Heeft u verder nog opmerkingen over dit scenario (het hele circuit)?

....

....

....

....

....

De volgende vragen gaan over het circuit met de fout in de snelheidsindicator, dus **Scenario 2**.

Mental Demand How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

Very low Very high

How surprised were you when you discovered the apparent change in speed?

Not at all	Slightly	Moderately	Very	Extremely

How well did the apparent change in speed fit into your "mental picture" of the upcoming events?

Very poorly	Slightly	Moderately	Well	Very well

How difficult was it to understand what had happened?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How difficult was it to think of the potential consequences of the apparent change in speed for the rest of the flight?

Not difficult	Slightly difficult	Fairly difficult	Difficult	Very difficult

How did you have to change your plans for the rest of the flight?

Very little	Somewhat	Moderately	Seriously	Very seriously

How startled or shocked were you when you discovered the apparent change in speed?

Not at all	Slightly	Moderately	Very	Extremely

How much tension or anxiety did you feel while you solved this problem?

Extremely little ———————————————— Maximum

De volgende vragen gaan over de training in haar geheel. De training bestond uit zes maal een engine failure tijdens take-off en acht fly-by's over de baan.

	Not at all true			Somewhat true			Very true
This training was fun to do.	1	2	3	4	5	6	7
I would describe this training as very interesting.	1	2	3	4	5	6	7
This training did not hold my attention at all.	1	2	3	4	5	6	7
I thought this training was quite enjoyable.	1	2	3	4	5	6	7
While I was doing this training, I was thinking about how much I enjoyed it.	1	2	3	4	5	6	7
I thought this was a boring training.	1	2	3	4	5	6	7
I enjoyed doing this training very much	1	2	3	4	5	6	7

Heeft u verder nog opmerkingen over de training?

....

....

....

....

....

Bedankt voor het invullen van de vragenlijst.

Appendix C

Scenarios

This appendix contains the details of all 20 scenarios used for this experiment. This includes the situations at the start, the task given to the pilot and the constant and changing conditions for each scenario.

The contents from the scenario files, which define events and conditions and are loaded by the simulation (ECI module), is included.

C-1 Familiarization

Start: Stationary on EHAM runway 18C with 3000 ft of runway available.

Task: Perform a left-handed circuit at 1000 ft and 130 kts. Best climb speed is 92 knots and the approach speed is 85 kts. Takeoff is performed without flaps and the landing with 25° flaps.

Constant conditions: 100 km visibility and scattered clouds.

Variation: Familiarization 2 contains light crosswind from 90° (left).

Contents of scenario file "101_familiarization_1.sce":

```
# Scenario
id       101
inco     EHAM_18C_3000ft.inco

windEvent
eventtime        0    from the start
enable_turb      0
turb_int         0
wind_vel         0    m/s
wind_dir         0    deg
enable_windshear     0
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud0_alt        10000    ft # 0=SCT 1=BKN 2=OVC
```

Contents of scenario file “102_familiarization_2.sce”:

```
# Scenario
id      102
inco    EHAM_18C_3000ft.inco

# familiarization_1 + x-wind

windEvent
eventtime        0
enable_turb      0
turb_int         0
wind_vel         5
wind_dir         90
enable_windshear    0
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC
```

C-2 Pre- and post-test

Start: Lined up in front of the runway at an altitude of 680 ft with an airspeed of 81 kts. The aircraft is already configured for landing, with the landing gear down and the flaps in the approach position (25°).

Task: Perform an approach and landing without a functional rudder. As the nose-wheel steering is also not functional a nose-up landing is preferred.

Constant conditions: Moderate crosswind from 90° (left), 100 km visibility and scattered clouds.

Event: After 60 seconds into the scenario the rudder deflection is fixed at 0.1°.

Contents of scenario file “201_pretest_1.sce”:

```
# Scenario
id      201
inco    EHAM_18C_app2m.inco


# Approach + landing
# Crosswind (5 m/s, 90 graden)
# Rudder fixed at 0.1 degrees after 60 seconds
# was:
# Ailerons 25 % effective after 60 seconds


windEvent
eventtime           0
enable_turb         0       0=false 1=true
turb_int            0
wind_vel            7       m/s
wind_dir            90      degrees; 0=north
enable_windshear    0       0=false 1=true
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC




controlEvent
eventtime       60      seconds from the start
aileron_power   1       effectiveness [0-1]
rudder_power    1       effectiveness [0-1]
rudder_bias     0.1     fixed angle in degrees; -15 to 15 (hardcoded max from -35 to 35)
ARI             0       aileron-rudder-interconnect; aileron input added to rudder output [0-1]
```

Contents of scenario file “602_post_test_2.sce”:

```
# Scenario
id       602
inco     EHAM_18C_app2m.inco


# SAME AS PRETEST


windEvent
eventtime            0
enable_turb          0        0=false 1=true
turb_int             0
wind_vel             7        m/s
wind_dir             90       degrees; 0=north
enable_windshear     0        0=false 1=true
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud0_alt        10000    ft # 0=SCT 1=BKN 2=OVC


controlEvent
eventtime        60       seconds from the start
aileron_power    1        effectiveness [0-1]
rudder_power     1        effectiveness [0-1]
rudder_bias      0.1      fixed angle in degrees; -15 to 15 (hardcoded max from -35 to 35)
ARI              0        aileron-rudder-interconnect; aileron input added to rudder output [0-1]
```

C-3 Training: Single engine failure on take-off

Start: Stationary on EHAM runway 18C with 3000 ft of runway available.

Task: Perform a take-off and climb to 500 ft altitude.

Constant conditions: Light crosswind from 90° (left), 100 km visibility and scattered clouds.

Variations: See Table C-1.

Table C-1: Variations for the first training topic: A single engine failure on take-off

Scenario ID:	301	302	303	304	305	306
At altitude (ft)	-	-	4.5	270	-	310
At speed (kts)	-	65	-	-	-	-
At gear position (0-1)	0.95	-	-	-	0.5	-
Power left (0-1)	0	1	1	1	0	1
Power right (0-1	1	1	0	0	1	0
Power adjustment (s)	1	-	1.1	1	1	1
Max. RPM left	2800	2800	2800	2800	2800	2800
Max. RPM right	2800	1500	2800	2800	2800	2800

Contents of scenario file “301_training_1_1.sce”:

```
# Scenario
id       301
inco     EHAM_18C_3000ft.inco

windEvent
eventtime        0    from the start
enable_turb      0
turb_int         0
wind_vel         3    m/s
wind_dir         90   deg
enable_windshear     0
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud0_alt        10000    ft # 0=SCT 1=BKN 2=OVC
```

```
# Training 1: Engine failure on takeoff
# Extra s 2: Engine failure links bij gear up.
# - alleen commando gear up of ook echt het gear ophalen? momenteel het laatste
#
# if gear comes up, beyond 0.95
# power of left engine decreases to 0
# in 1 second

dummyEvent
eventtime           2       make sure the next event does not immediately trigger (possible bug in
    model)
# this bug with the landing gear should be fixed by now

engineEvent
eventgear           0.95    gear coming up
power_left          0       no power available
engine_time_left    1       time in seconds
#
# others are default, just listed here for easy editing
#
power_right         1
max_rpm_left        2800
max_rpm_right       2800
engine_time_right   0
```

Contents of scenario file “302_training_1_2.sce”:

```
# Scenario
id      302
inco    EHAM_18C_3000ft.inco

windEvent
eventtime       0   from the start
enable_turb     0
turb_int        0
wind_vel        3   m/s
wind_dir        90  deg
enable_windshear    0
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC


# Training 1: Engine failure on takeoff
# Extra s 1: Engine failure op 65 kn (2800 rpm L, 1500 rpm R).
#
# if airspeed reaches 65 kts
# rpm of right engine drops to 1500

engineEvent
eventspeed          65      kts
max_rpm_right       1500    RPM drop
#
# others are default, just listed here for easy editing
#
power_left          1
power_right         1
max_rpm_left        2800
engine_time_left    1.1
engine_time_right   1.1
```

Contents of scenario file “303_training_1_3.sce”:

```
# Scenario
id      303
inco    EHAM_18C_3000ft.inco

windEvent
eventtime       0   from the start
enable_turb     0
turb_int        0
wind_vel        3   m/s
wind_dir        90  deg
enable_windshear    0
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC

# Engine failure on rotate.
# if plane comes off the ground
# power of right engine decreases to 0
# in 1 second

engineEvent
eventaltitude       4.5     ft (reference point starts at ~4 ft)
```

```
power_right         0       no power available
engine_time_right   1.1     time in seconds
#
# others are default, just listed here for easy editing
#
power_left          1
max_rpm_left        2800
max_rpm_right       2800
engine_time_left    0
```

Contents of scenario file "304_training_1_4.sce":

```
# Scenario
id      304
inco    EHAM_18C_3000ft.inco

windEvent
eventtime       0   from the start
enable_turb     0
turb_int        0
wind_vel        3   m/s
wind_dir        90  deg
enable_windshear    0
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC


# Training 1: Engine failure on takeoff
# Extra s 4: Engine failure rechts in climb (na gear up, 100 kn)
#- currently set at 100 kts
#   NOTE ideal climb speed might me less than 100
#
# if airspeed reaches 100 kts
# power of right engine decreases to 0
# in 1 second

engineEvent
eventaltitude       270     ft (reference point starts at ~4 ft)
power_right         0       no power available
engine_time_right   1       time in seconds
#
# others are default, just listed here for easy editing
#
power_left          1
max_rpm_left        2800
max_rpm_right       2800
engine_time_left    0
#
# other triggers
#eventgear          0.1     gear is almost up
#eventaltitude      100     ft
```

Contents of scenario file "305_training_1_5.sce":

```
# Scenario
id      305
inco    EHAM_18C_3000ft.inco

windEvent
eventtime       0   from the start
enable_turb     0
turb_int        0
wind_vel        3   m/s
wind_dir        90  deg
enable_windshear    0
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud0_alt       10000   ft # 0=SCT 1=BKN 2=OVC


# Training 1: Engine failure on takeoff
# Extra s 5: Engine failure links bij gear up.
#
# if gear comes up, beyond 0.5 (halfway, 3 seconds in)
# power of left engine decreases to 0
# in 1 second

dummyEvent
eventtime           2       make sure the next event does not immediately trigger (possible bug in
    model)

engineEvent
eventgear           0.5     gear half up
power_left          0       no power available
engine_time_left    1       time in seconds
```

```
#
# others are default, just listed here for easy editing
#
power_right          1
max_rpm_left         2800
max_rpm_right        2800
engine_time_right    0
```

Contents of scenario file "306_training_1_6.sce":

```
# Scenario
id       306
inco     EHAM_18C_3000ft.inco

windEvent
eventtime         0    from the start
enable_turb       0
turb_int          0
wind_vel          3    m/s
wind_dir          90   deg
enable_windshear       0
# visibility and clouds
fg_visibility          100000   in meters
fg_cloud0_alt          10000    ft # 0=SCT 1=BKN 2=OVC

engineEvent
eventaltitude          310      ft (reference point starts at ~4 ft)
power_right            0        no power available
engine_time_right      1        time in seconds
```

C-4 Training: Rudder hardover and flyby

Start: Lined up in front of the runway at an altitude of 720 ft with an airspeed of 99 kts. The landing gear is down and the flaps are in the approach position (25°).

Task: Fly towards the runway with the current airspeed. Then perform a flyby over the runway centerline at an altitude of 100 ft and an airspeed of 85 kts. Try to not get under this altitude and airspeed. The configuration cannot be changed.

Variations: See Table C-2. The participants in Group 2 were further instructed to increase their airspeed halfway during the flyby.

Table C-2: Variations for the second training topic: A rudder hardover and fly-by

Scenario ID:	421	422	423	424
Turbulence intensity	0	0	0.15	0.15
Wind velocity (m/s)	7	7	7	7
Wind direction (deg)	270	180	90	270
Visibility (m)	100000	100000	9000	9000
Clouds	SCT	SCT	OVC	OVC
Event time (s)	20	50	50	30
Rudder deflection (deg)	15	20	25	10

Contents of scenario file "411_training_3_1.sce":

```
# Scenario
id       411
inco     EHAM_18C_app2m_99kts.inco

windEvent
eventtime         0    from the start
enable_turb       0
turb_int          0
wind_vel          7    m/s
```

```
wind_dir          270 deg
enable_windshear      0
# visibility and clouds
fg_visibility         100000   in meters
fg_cloud0_alt         10000    ft # 0=SCT 1=BKN 2=OVC

controlEvent
eventtime         20
rudder_bias       15
```

Contents of scenario file "412_training_3_2.sce":

```
# Scenario
id        412
inco      EHAM_18C_app2m_99kts.inco

windEvent
eventtime         0   from the start
enable_turb       0
turb_int          0
wind_vel          7   m/s
wind_dir          180 deg
enable_windshear      0
# visibility and clouds
fg_visibility         100000   in meters
fg_cloud0_alt         10000    ft # 0=SCT 1=BKN 2=OVC

controlEvent
eventtime         50
rudder_bias       20
```

Contents of scenario file "413_training_3_3.sce":

```
# Scenario
id        413
inco      EHAM_18C_app2m_99kts.inco

windEvent
eventtime         0   from the start
enable_turb       1
turb_int          0.15
wind_vel          7   m/s
wind_dir          90  deg
enable_windshear      0
# visibility and clouds
fg_visibility         9000     in meters
fg_cloud2_alt         10000    ft # 0=SCT 1=BKN 2=OVC

controlEvent
eventtime         50
rudder_bias       25
```

Contents of scenario file "414_training_3_4.sce":

```
# Scenario
id        414
inco      EHAM_18C_app2m_99kts.inco

windEvent
eventtime         0   from the start
enable_turb       1
turb_int          0.15
wind_vel          7   m/s
wind_dir          270 deg
enable_windshear      0
# visibility and clouds
fg_visibility         9000     in meters
fg_cloud2_alt         10000    ft # 0=SCT 1=BKN 2=OVC

controlEvent
eventtime         30
rudder_bias       10
```

C-5 Training: Single engine failure and flyby

Start: Lined up in front of the runway at an altitude of 720 ft with an airspeed of 99 kts. The landing gear is down and the flaps are in the approach position (25°).

Task: Fly towards the runway with the current airspeed. Then perform a flyby over the runway centerline at an altitude of 100 ft and an airspeed of 85 kts. Try to not get under this altitude and airspeed. The configuration cannot be changed.

Variations: See Table C-3. The participants in Group 2 were further instructed to increase their airspeed halfway during the flyby.

Table C-3: Variations for the third training topic: A single engine failure and fly-by

Scenario ID:	421	422	423	424
Turbulence intensity	0	0.15	0	0.15
Wind velocity (m/s)	5	5	5	5
Wind direction (deg)	270	270	90	90
Visibility (m)	100000	100000	9000	9000
Clouds	SCT	SCT	OVC	OVC
Event time (s)	20	40	30	50
Power left (0-1)	0	1	0	1
Power right (0-1	1	0	1	0
Power adjustment (s)	1.1	1.1	1.1	1.1

Contents of scenario file “421_training_2_1.sce”:

```
# Scenario
id       421
inco     EHAM_18C_app2m_99kts.inco

windEvent
eventtime        0    from the start
enable_turb      0
turb_int         0
wind_vel         5    m/s
wind_dir         270  deg
enable_windshear     0
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud0_alt        10000    ft # 0=SCT 1=BKN 2=OVC

engineEvent
eventtime        20
power_left       0    no power available
engine_time_left     1.1  time in seconds
```

Contents of scenario file “422_training_2_2.sce”:

```
# Scenario
id       422
inco     EHAM_18C_app2m_99kts.inco

windEvent
eventtime        0    from the start
enable_turb      1
turb_int         0.15
wind_vel         5    m/s
wind_dir         270  deg
enable_windshear     0
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud0_alt        10000    ft # 0=SCT 1=BKN 2=OVC

engineEvent
eventtime        40
power_right      0        no power available
engine_time_right    1.1      time in seconds
```

Contents of scenario file "423_training_2_3.sce":

```
# Scenario
id       423
inco     EHAM_18C_app2m_99kts.inco

windEvent
eventtime        0    from the start
enable_turb      0
turb_int         0
wind_vel         5    m/s
wind_dir         90   deg
enable_windshear     0
# reduced visibility and clouds
fg_visibility        9000     in meters
fg_cloud2_alt        10000    ft # 0=SCT 1=BKN 2=OVC

engineEvent
eventtime        30
power_left       0        no power available
engine_time_left     1.1      time in seconds
```

Contents of scenario file "424_training_2_4.sce":

```
# Scenario
id       424
inco     EHAM_18C_app2m_99kts.inco

windEvent
eventtime        0    from the start
enable_turb      1
turb_int         0.15
wind_vel         5    m/s
wind_dir         90   deg
enable_windshear     0
# reduced visibility and clouds
fg_visibility        9000     in meters
fg_cloud2_alt        10000    ft # 0=SCT 1=BKN 2=OVC

engineEvent
eventtime        50
power_right      0        no power available
engine_time_right    1.1      time in seconds
```

C-6 Unrelated surprise test

Start: Stationary on EHLE runway 05 with the full (4000 ft) runway available.

Task: Perform a left-handed circuit at 1000 ft and respond to a problem.

Conditions: moderate crosswind from 340° (left), 100 km visibility and broken clouds.

Event: When reaching an altitude of 10 ft, the indicated airspeed starts to drop with 1 knot/s compared to the actual airspeed.

Contents of scenario file "501_training_4.sce":

```
# Scenario
id       501
inco     EHLE_05.inco

# set wind and turbulence
windEvent
eventtime            0
enable_turb          0        0=false 1=true
turb_int             0
wind_vel             7        m/s
wind_dir             340      degrees; 0=north
enable_windshear     0        0=false 1=true
# visibility and clouds
fg_visibility        100000   in meters
fg_cloud1_alt        10000    ft # 0=SCT 1=BKN 2=OVC


# op 6 voet, na ~10 voet klimmen,
# loopt de aangegeven snelheid terug met 1 knoop/s
```

```
displayEvent
eventaltitude       10      ft (reference point starts at ~4 ft)
frozen_v            0       =false
frozen_h            0       =false
offset_v_value      -200        offset
offset_v_time       200     time in seconds
offset_h_value      0       offset
offset_h_time       0       time in seconds
```

C-7 Related surprise test

The same start, task and conditions as the unrelated test.

Events:

- When reaching an airspeed of 55 knots, the power available on the right engine reduces to 40% over a period of 20 seconds.
- When reaching an altitude of 490 ft, the power available on the left engine reduces to 50% over a period of 4 seconds.
- 6 seconds after starting the previous event, the power available on the left engine returns to 100% over a period of 1 second. This is 2 seconds after the left engine reaches minimal power.
- When rolling out of the turn going into the downwind leg (around heading 240, as downwind is heading 230), the rudder effectiveness reduces to 20%. Because of these requirements on the timing of the event, this event is triggered manually by pressing a button.

Contents of scenario file “601_post_test_1.sce”:

```
# Scenario
id      601
inco    EHLE_05.inco


#-- part 1 ---

# set wind and turbulence
windEvent
eventtime           0
enable_turb         0       0=false 1=true
turb_int            0
wind_vel            7       m/s
wind_dir            340     degrees; 0=north
enable_windshear    0       0=false 1=true
# visibility and clouds
fg_visibility       100000  in meters
fg_cloud1_alt       10000   ft # 0=SCT 1=BKN 2=OVC


# starting from 55 kts, reduce right engine power to 40%, in 20 seconds
engineEvent
eventspeed          55      kts
power_right         0.4     reduced power
engine_time_right   20      time in seconds
# more options, unchanged
power_left          1
max_rpm_left        2800
max_rpm_right       2800
engine_time_left    0


# at 490 ft, reduce the power on the other engine to 50% in a few seconds
# after 2 seconds, go back to 100% power in 1 second
engineEvent
eventaltitude       490
```

```
power_left          0.5
engine_time_left    4

engineEvent
eventtime_after     6         4+2
power_left          1
engine_time_left    1


# continue climb and fly circuit back to runway
#-- part 2 ---
# rudder effectiviteit naar 20%

controlEvent
eventtime           1000      #TODO bedenk een goede trigger
#
@button_press       manual
#
aileron_power       1
rudder_power        0.2
rudder_bias         0
ARI                 0
```

Appendix D

Readme on defining scenario in the simulation

The following text is from the README file found in the scenario directory of the project (`run/run-data/scenarios/`). It describes how scenarios are defined in plain text files, listing the available event triggers and options. These files are loaded by the ECI module, which then plays the event automatically. This gives the same events at the same triggers every time the scenario is played.

```
# README on scenario files

A scenario file defines one or more events that take place during the simulation

The ECI looks for all files ending with .sce and lists them in the file selection list.

When selected and after pressing the "Send" button, the first event of the scenario is loaded from
    file.

After sending out an event, the next event is loaded.

The ECI GUI gives the parameters loaded from file at that specific time, waiting to be send.

Comments can be added by starting the line with a #.

Do not starts lines with spaces of tabs, these lines will be ignored too.


### HEADER ###

At the top of the sce-file, two items have to be defined, in this order:

id          integer marking the scenario, for keeping them apart (logging)
inco        full name of the inco file (incofile.inco)


Numbering used for the scenario id
Familiarization 10x
Pre-test        20x
Training 1      30x
Training 2      41x
Training 3      42x
Distraction     501
Post-test       60x


### EVENTS ###
```

```
Next, and separated by at least one empty line, follow the events. Events end with at least one empty line, also the last event! Don't use empty lines

The first line of the event defines the event type(s), after that the order of items does not matter.

Syntax of the settings/parameters lines
parameter name <space/tab> value <space/tab> optional comments


## Event types

Can be one, or multiple, of the following:

controlEvent,massEvent,engineEvent,windEvent,displayEvent


## Event trigger

These triggers are defined:

eventtime               event at time from start [s] (float)
eventtime_after         event at time after previous event [s] float
eventspeed              event at or above this speed [kts] (float)
eventaltitude           event at or above this altitude [ft] (float)
eventgear               event at or below this gear position, when retracting (float)

each event needs to at least define a trigger, or else nothing will happen

Testing with manual trigger @button_press


## Event parameters

Also see the example scenarios
The listed numbers are the default (nominal) values in the ECI

# settings for an engineEvent (all floats)
power_left          1.0     0=none 1=full
power_right         1.0     0=none 1=full
max_rpm_left        2800    rpm limit, nominal is 2800
max_rpm_right       2800    rpm limit, nominal is 2800
engine_time_left    0.0     time in seconds for power change
engine_time_right   0.0     time in seconds for power change

# settings for a massEvent (all floats)
shift_x             0.0     meters to the front (if positive)
shift_y             0.0     meters over the right wing (if positive)
shift_z             0.0     meters down (positive) or up (negative)
shift_mass          0.0     kg
shift_time          0.0     seconds

# settings for a windEvent (due to additions, a better name would be weatherEvent)
enable_turb         0       (bool) 0=false 1=true
turb_int            0.0     (float) 0 to 1.5
wind_vel            0.0     (float) wind velocity in m/s (not exact)
wind_dir            0.0     (float) direction where the wind comes from in degrees; 0=north
enable_windshear    0       (bool) 0=false 1=true
fg_visibility       100000  (int) visibility in meters
#TODO clouds if needed

# settings for a controlEvent (all floats)
aileron_power       1.0     effectiveness [0-1]
rudder_power        1.0     effectiveness [0-1]
rudder_bias         0.0     fixed angle in degrees; -15 to 15 (hardcoded max from -35 to 35)
ARI                 0.0     aileron-rudder-interconnect; aileron input added to rudder output [0-1]

# settings for a displayEvent
frozen_v            0       0=false 1=true
offset_v_value      0.0     offset in knots
offset_v_time       0.0     time in seconds
frozen_h            0       0=false 1=true
offset_h_value      0.0     offset in ft
offset_h_time       0.0     time in seconds


### NOTES ###

Only parameters which are part of the listed event will be send out. So it is possible to load all parameters at the top, and then send events one by one. The ECI GUI displays the currently loaded values, the Malfunctions GUI displays the implemented settings.
```

Appendix E

Changes made in the SenecaTraining project

The following text contains an overview of part of the changes made to the project. This text is also included in the file NOTE in the root directory of the SenecaTraining project on the DUECA repository. It is thus included when performing a project checkout.

```
This project is based on the Asym1 project.
This file contains an overview of some changes made.

Known issues (code):
- in ../SRSMotion/comm-objects/MotionBaseResultData.dco rename u_int32_t to uint32_t
- multiple rt_nonfinite.c / rt_nonfinite.h, remove from MotionFiltersRTW70/motion-filter-classical
    -16


Overall:
- Use of D_MOD, I_MOD, W_MOD and E_MOD instead of cout
- motion filter updated to the latest version which is compatible with the PA34 model (RTW70)
- removed unused module ConventionalDisplay
- GUIStick borrowed to be able to start the sim without a joystick


comm-objects:
- own copy of MalfunctionsChannel
- (concept) new channel EngineData; can be used for data from model to engine display
- INCOSelect event channel; let other modules select the inco file
- MalfunctionsChannel.dco; replaced by MassEvent.dco, ControlEvent.dco, EngineEvent.dco
- Added DisplayEvent.dco
- EngineEvent.dco; option to have partial engine power, adjustment time for change
- CitationExample channel TurbulenceConfiguration.dco replaced by WindEvent.dco


B747DisplaysCommonFiles:
(no changes made, equal to files in B747Approach project)


B747PFD:
- code cleanup
- option do-cv-calculation added
- read DisplayEvent channel, vel/alt indicator frozen or offset
- show heading, speed and altitude bugs based on MCP settings
-TODO: move heading indicator back down (or make the location an option)
- all speed limits updated from aircraft manual
- added DEG2RAD conversion to trackAngle


CitationIncoSelector:
- updated GUI to make better use of the space + spelling/layout fixes
- read the INCOSelect event channel, load specified inco file
- readInco(): do not allow comments in between inco conditions
```

```
- change of wind/turb channel, made function which is called from different locations


CitationLogger:
- Note that CitationReplayer is not working in the current setup
- code cleanup
- option do-cv-calculation added
- channels changed
- write extra data to header of log file
- items logger and their order changed
- commented out the optional Vc_Channel channel, as data is not logged


CitationLogger - Replayer:
(manually select corresponding scenario in ECI)
- modified to work with our log files
- updated channels and data send over these channels
- time step obtained from file can be wrong, check added
- token for MassEvent "feedback" added, so the Malfunctions module works (no data yet)


CitationModelInclude:
- updated names of enum items to represent their current use (e.g. torque instead of ff)
-TODO check if anything apart from StatesOutputs.h is used (see TODO file)


CitationNavigator:
- nd.speed_ref default value changed from 97 to 0


CommsVisualize:
- Pseudo-module for holding a script to generate an image of the communications within this project


CvCalculation:
- no changes made in the code
- comm-objects file updated to use "SenecaTraining/comm-objects/MalfunctionsChannel.dco"
- module can be included/excluded using the switch do-cv-calculation in dueca.mod
- module removed due to channel changes (no use for me to update)
REMOVED
- re-copied this module from the Asym1 project, for Herman (and to see if it would still work)
- removed all reading from MalfunctionsChannel
- enable this module using the switch do-cv-calculation in dueca.mod


ECI:
- new module for the Experiment Control Interface
- uses the scenario files stored in the run-data folder
- sends INCOSelect event to CitationIncoSelector for loading inco
- rewrite of sce-file reader: "unlimited" number of events possible
- reset added for settings (also send out into sim) and GUI
- DisplayEvent support added
- more event triggers added
- proper handling of boost::bad_lexical_cast errors


Malfunction:
- bugfix: logged values for aileron_power, rudder_power and rudder_bias might be wrong
- GUI update to group items
REMOVED


Malfunctions:
- New module replacing Malfunction
- change buttons from GtkToggleButton (an on/off button) to GtkButton
- add buttons to CallbackTable
- GUI values are updated to indicate current malfunction status
- GUI values are directly linked to channels, no storage in variables


PA34:
- code cleanup
- removed duplicate code
- mass shift (malfunction) can be (re)set in SimulationState::HoldCurrent
- turbulence and wind event handling
- mass shift and con_trol settings are only implemented if their respective boolean is true (instead
     of on boolean changed)
- gear and flaps movement stopped before the commanded position
- BUG mass shift can go crazy; solved by checking steps>0 and setting teller=0 on incoming event
  - updated mass shift code
- Minimal wind speed with turbulence reduced from 10 m/s to 1 m/s
- Gear timings set to 6 seconds, according to manual Section 7.9 which states:
  - "Gear extension or retraction normally takes 6 to 7 seconds."
  - made indepentant of sim timing
- Flaps set to move "1 rad per 7 seconds",
  - but now uses dt (so independent of sim timings)
  - full deflection in 4.9 seconds, which is 5% more than old hardcoded time at 100Hz timings
- flaps and gear position have their own variable, instead of getting them from the model input
    vector. should solve a bug
- flap-speed and gear-time options added to dueca.mod
```

```
- fade_in (motion) also used for sound (rpm) to WAVPlayer
- slowly change the wind velocity input to the model to prevent extreme forces (only a problem when
    on the ground)
  - reset to zero when a new model is loaded
  - (should be done in wind model itself)
  - also added for the wind direction, only used if there already is wind in the model

PA34 Simulink:
- TODO add additional inputs and outputs, see TODO
- BUG in breaking system / engine failure. Breaks are applied on engine failure.
  - break force negatively proportional to left throttle setting
Known issues:
- group behaviour can be unrealistic
- wind model is very basic. given input velocity is not in exact units


PA34_engine:
- adjusted position of text in display
- update of logic / code cleanup
- recalibrated RPM indicator (had an 125 to 200 rpm offset)

ScoreCalculator:
- New module to calculate the pilot score. RMS of centerline deviation.


WAVPlayer:
- added module for engine sound playback
- sound pitch depends on RPM
- sound gain depends on torque

WeatherProxy:
- New module to centrally send weather updates to FGWeather, based on input from the WindEvent
    channel
- Keeps the previous settings, so not all values have to be included in a WindEvent

________
Some additional borrowed modules:


CitationDemo/FGVisual
- module for sending the position and attitude details to FG
- start FG using "./start_fg.sh", before starting DUECA
- start both using "./start_fg.sh 1" instead of "../../../dueca_run.x"

HapticFlightEnvelopeProtectionTestBench/FGWeather
- module for sending weather details to FG
- initially used to set the windsocks in FG correct based on the wind in the model
```

Appendix F

To-do list for the SenecaTraining project

The following text contains the to-do items for the SenecaTraining project which could be implemented in future versions, including proposals for the Seneca Simulink model. Listed in the bottom part of the list are item that were listed and have been implemented. This text is also included in the file TODO in the root directory of the SenecaTraining project on the DUECA repository. It is thus included when performing a project checkout.

```
--- TODO ---

Replayer
- write to DisplayEvent.dco (WindEvent.dco: fgweather data is missing in log)
  - can be solved by selecting the right scenario in the ECI
- GUI to select log file and point on timeline (iterator + integer -> +=/-=)

ECI (partially done)
- feature: manually send event (option: time=inf, on button press time=now)
  - new trigger @button_press
  - on sce read: make send button active for this event
  - on button press, check if in active or hold; if in active set time=now
  - deactivate send button
- button always disables when changing state to advance
- current setup requires some spaces after @button_press, else it skips the following line

ECI
- the cloud settings are hacked in at the moment, could use some cleaning up

CitationLogger
- add flightgear weather data to log (for replay)
- WORKAROUND: load the right sce file prior to starting the replay




--- MAYBE LATER ----

WAVPlayer
- add wind
- add gear sounds
- add alarms
- add bang

ECI:
- feedback to GUI in case an error was caught while loading a scenario from file (currently output
    with E_MOD)
- add hold request option to end scenario from sce file
- Start all triggers with an @ to make them stand out
@totaltime          10       time since start
```

```
@addedtime          3       time since last event
@speed_above        65      knots
@alt_above          10      ft
@gear_to_up         0.5     when gear is halfway going up
- have a comment option which will be displayed in the ECI section

Malfunctions:
- just like for the mass shift, display the currently implemented values for
  - engine
  - display (also give the actual values)

ControlEvent.dco:
- implemented the unused items of this channel

Simulink model
- output: add fuel qty in tanks
- input: option to set initial fuel qty
- input: delta/offset on altitude or air pressure in atmospheric model (now ISA, based on altitude)
  - atmos model: Aircraft Model -> Models -> Atmospherical model : calculates rho, T, g, and wind
      values
- input: co-efficient of friction of the runway (mu_roll, mu_side in ground model)
- do in C++ instead of in simulink
  - rudder hardover
- breaking as separate input, not based on throttle setting
  - or at least have differential breaking, instead of all breaks on the left throttle
  - in the current implementation the wheels seem to simply block, allowing for easy side movements/
      sliding
- wind: slowly change wind velocity and direction, instead of in one timestep, to avoid almost
    infinite forces
  - currently implemented in C++ code in PA34 module
- check indicated airspeed if neutral on runway with tailwind, windspeed added regardless of
    direction
- rudder hardover directly influences nosewheel steering on the ground
- the behaviour on the ground can be "weird", for example it might shoot into the air

Engine display, add new streamchannel to have data for all things on the engine display
- for all PA34_engine data, set all data (incl. dummy) in PA34 module
- see EngineData.dco

CitationModelInclude is not required, apart from StatesOutputs.h
- CitationIncoSelector includes Citation.h, which includes a bunch of other citation code
- move StatesOutputs.h to other directory (PA34?)
- update all relevant makefiles of modules
- update CitationIncoSelector which uses headers from CitationModelInclude, to include the Seneca
    model headers instead
- Make a Seneca Simulink/RTW model pseudo-module

CitationLogger: all log files to log directory

additional control malfunctions
- fixed aileron deflection ? (like rudder hardover)
- elevator malfunctions

Make a malfunction influence the control loading
- fix rudder pedals, free moving pedals (change qfeel?)

CitationIncoSelector:
- also add current altitude and heading indication in GUI

PA34, IncoSelector and inco files
- terrain elevation, use the setting in the model instead of FlightGear setting
- this way it can be more dynamic based on the current location
- corresponding with ISA (not really a problem in NL)

Malfunction
- read only / slave mode



--- DONE and KEEP ---

motion filter change:
- added MotionFiltersRTW70/motion-filter-classical-12 HEAD to modules.solo
- took config from Asym1 SRS dueca.mod (all noted down with comments and TODO)
- added include andy motion files (added .cnf to links.script)
- commented out the incompatible old code in SenecaT solo dueca.mod
- cleanup andy_motion_filt.cnf
- DROPBOX is case insensitive, removed link to have code in dropbox
- MotionBaseResultData.dco en DUECA2: u_int32_t changed to uint32_t

Error when having motion enabled after motion-filter update
--
08:56:54.093332 eMOD ML InitialPrepared failed: Communication to MCC unavailable
08:56:54.093414 iMOD MotionLimiter is not initial prepared
--
>> solved: 'fake-io #t ;;(not use-motion)

proper use of D_MOD, I_MOD, W_MOD, E_MOD to reduce the clutter in the terminal output
- clean up output to terminal in general
```

```
cv-calculation, option to disable
- option in PFD and CitationLogger modules to not read from the channel, set in dueca.mod and use VarProbe
- remove cv-calculation from dueca.mod (to not load module) >> added bool do-cv-calculation instead
- current situation: if database>2, cv-calc writes negative data (-value) so it is logged but not displayed
>> added to dueca.mod " 'read-cv-channel do-cv-calculation
>> no change in the logged data format, default vars used for cv data

Bug with Malfunctions/CitationLogger interaction
- logged values for aileron_power, rudder_power and rudder_bias might be wrong
- latest values logged, however these are only implemented after pressing the button (not checked)
- occurs when changing them in the GUI, and then doing something else (not pressing the apply button) that sends an event
  - always latest input is send out
- not for c.g. shift values; because the implemented values from AsymmetryChannel are logged

Add scenario files to repository

PA34 model: reading of the malfunctions channel booleans - use true false instead of change

ECI - see requirements list in Prelim report
- (module source started)
- read config file
- define config file contents, refer to inco file?
- make new module - see DraftSimExp/ECI
- Glade; get the right version and make a GUI (Glade 3.8 for GTK+ 2)
- write to channels
> see ideas in prelim report
> computers behind simona: Glade 2.12.2

Split up malfunctions channel into different channels - DisplayEvent, ... others
- dco made: MassEvent.dco, ControlEvent.dco, EngineEvent.dco

MalfunctionsChannel: all modules that write and read this channel
- use of float1 == float2
- booleans not always used as bools : implement if bool has changed -> implement if bool == true
- CitationLogger: always logs the latest data on channel, even if not actually used in model (for example aileron_power)
- change some items from floats to integers
REPLACED MalfunctionsChannel

ECI
- reset turbwind/malfunction when loading scenario (click send button) (option: reset button)
- feature: multiple events in scenario (option: load file with offset to line X)
- feature: change values in GUI - update Malfunction GUI for this instead; updates itself

DisplayEvent
- ECI & B747PFD

Turn module malfunction into a read and write module for all event channels -> as new module Malfunctions
Malfunction replaced by Malfunctions
- change buttons to "normal" buttons, add buttons to CallbackTable
- bug: Malfunctions module keeps sending out events because of the rounding thing
- feature: update items by reading MalfunctionsChannel

GUIs (Malfunction, IncoSelector)
- send initial values, so the data send is the right data (now displays 0 but sends other value)
- for example the ARI is set to zero the first time a malfunction event is send out, default set to 0.20 in dueca.mod
- SEE Malfunction

SRS working!

MotionFilters
- Update MotionFiltersRTW70/motion-filter-classical-12 to version -16
- set new version in andy_motion_filt.cnf

Malfunctions
- add DisplayEvent values
- removed all variables, directly link GUI to channels

adjustment time for RPM & throttle/pla limitation (ECI, Malf, PA34, Log, EngineEvent.dco)

INCOSelect.dco
-DONE add more items (notes made in ECI)
- also read by CitationLogger, write data to header

PA34 - set time for engine RPM adjustment

ECI
- add DisplayEvent values to GUI
- "GtkEntry" for notes, to send over INCOSelect

MotionFilters
- Check motion filter settings
-> Olaf approves of the motion
```

```
ECI
- To send engine failure at 70 knots, or have a speed_over option, just like eventtime
  - speed_over 70 : if (speed_over > 0 && current_speed > speed_over) send event!
  - DONE eventspeed, eventaltitude, eventgear, eventtime_after

PA34
- update mass shift "teller" and steps implementation to the one used for the display (because of
    bug in current system)
- currently 2 fixes used
- teller and steps merged

WAVPlayer
- take torque into account for engine sound

PA34 & Logger: Use feedback channels for logging actual implemented malfunction details
- [Done] massEvent
- [Done] engineEvent
- [Done] displayEvent -> in PFD
- No need for controlEvent, as there is currently no adjustment time / directly implemented

PA34: On SRS (not in solo) Gear starts in the up position when going to advance
- DONE by having a gear_pos variable, added more gear and flap settings

WindEvent.dco to replace the butchered implementation of using a citation channel with different
    items
- CitationIncoSelector, ECI, PA34, CitationLogger

StatesOutputs.h
- change names of items, especially those that should not be used

Weather data to FlightGear: set fixed values to ISA
- done in INCO Selector
- done in ECI

FGWeather
- both ECI and INCOSel. send out Weather events
- problem: they overwrite each other
- solution: make a WeatherProxy, which keeps currently set values, gets data, and sends out updates
  - expand and read current WindEvent
- only update local setting if change is specified (set default value in channel to -1)
-- first test, only if we actually use weather -- > well, we use the wind settings for sure

in run map: scriptje voor het ordenen van alle logbestanden, te runnen na iedere proefpersoon
- input: proefpersoon
- maak mapje
- verplaats alle 0*.log bestanden naar dit proefpersoon mapje
- maak extra bestand met gegevens over de logbestanden ?

B747PFD:
- move heading indicator back down (or make the location an option)
- found where to edit the code in constructor of compass.cxx and attitude_indicator.cxx

PA34:
- block changes to wind direction in advance, if wind velocity != zero
- how much work is it to add a rate to the direction change
- finish and test this rate limiter, else go back to a block if (v_wind > 0.1)
- works

< version used for experiment runs >

Fix the Citation replayer to work with the Seneca
- Only use the output modules, supply them with the right data (channels) from the logged data
- Has to write to channels:
  - DONE CitationOutput.dco, VehicleCabPosition.dco, VehicleCabMotion.dco, PropSoundData.dco
- copy output to channels from model file PA34 for
  - DONE VehicleCabPosition
  - DONE VehicleCabMotion
  - DONE PropSoundData

Tested implementation of elevator_fix (ControlEvent.dco, ECI, PA34)
```

Appendix G

Current layout of the DUECA project

This appendix contains an overview of the modules and channels used in the SenecaTraining project on a single node platform. Borrowed modules are indicated by the light grey boxes, while the dark grey boxes are own modules. The ellipses are channels, whereby the solid lines indicate stream channels and the dashed lines event channels. Blue lines indicate write actions to channels, while read actions are visualized using green lines. The red lines indicate there are both read and write actions between the module and channel.

Not included are the motion related items, the motion viewer and logger modules and their communication channels, and items only used on the SRS platform.

The figure is generated using a script that can be found in the pseudo-module CommsVisualize.

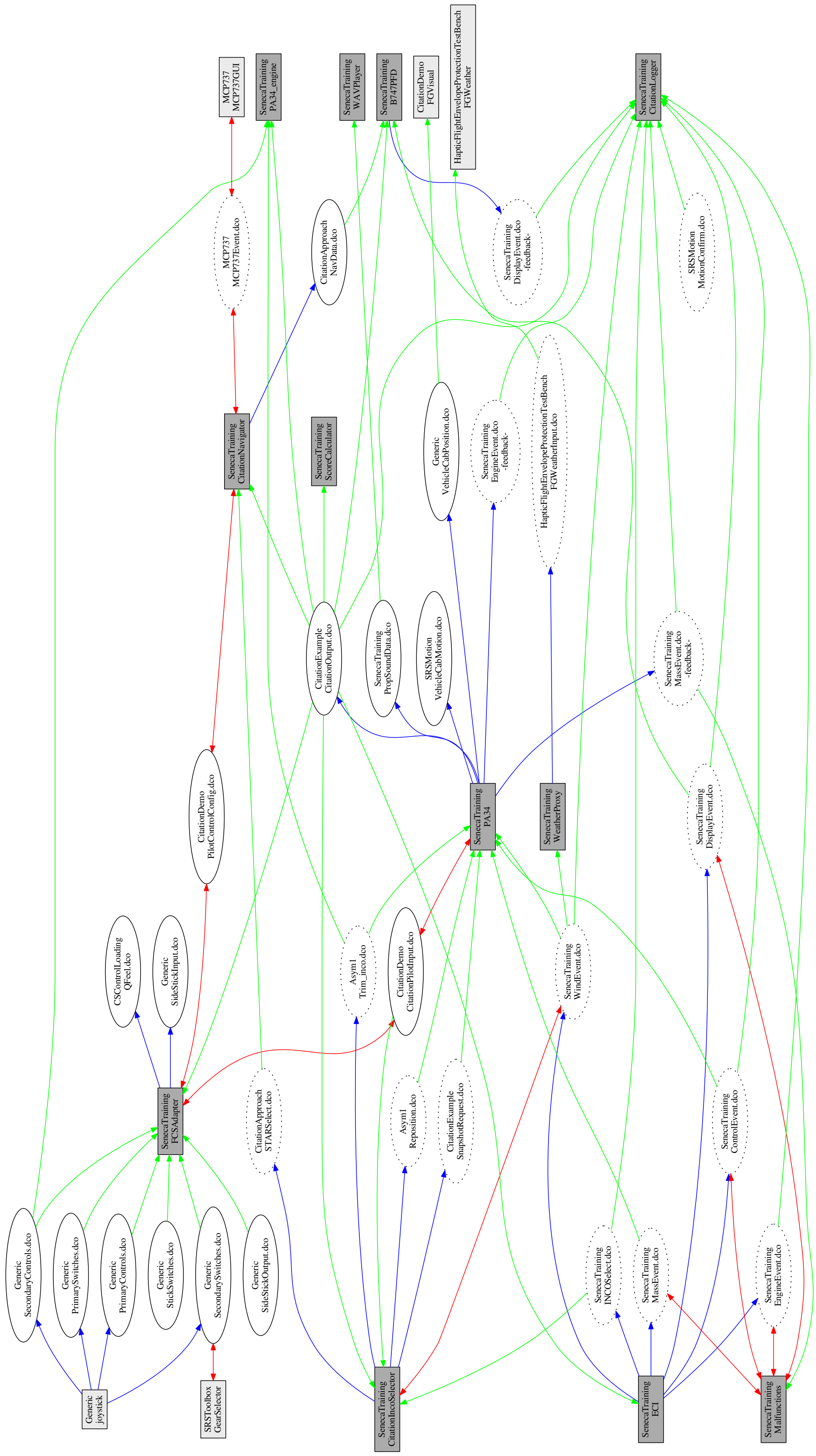

Figure G-1: Overview of modules and channels of the SenecaTraining DUECA project.