European Union Aviation Safety Agency

This project has received funding from the European Union's Horizon Europe Programme

EMCO SIPO EASA.2022.C17

D-2.2 DETAILED RESEARCH AND TEST ACTIVITY PLAN

eMCO-SiPO – Extended Minimum Crew Operations-Single Pilot Operations

An Agency of the European Union

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DELIVERABLE NUMBER AND TITLE:	eMCO-SiPO, D-2.2 Detailed Research and Test Activity Plan
CONTRACT NUMBER:	EASA.2022.C17
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IPR OWNER:	European Union Aviation Safety Agency
DISTRIBUTION:	Public

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DATE: 16.01.2023

SUMMARY

This report contains the detailed test plan for all simulator experiments assessing the effects of the introduction of the eMCO concept of operations (ConOps) on various characteristic human factors (HF) values like workload, situational awareness, decision making, boredom, fatigue, sleep inertia. The experiment results should enable the identification of possibly hazardous situations as well as a qualitative assessment of the reacheable level of safety. The report describes the general setup for all simulator experiments before detailing into the specific experiments for Nominal Operations (Task 2), Failure Conditions Management (Task 3), and Pilot Fatigue & Boredom and Sleep Inertia experiments (Task 4 + 6). The described experiments will be carried out from February to Mai 2024.

Problem area

Recent advancements in automation, technology, and unmanned autonomous aircrafts sparked interest in and a desire to investigate if it is possible to run commercial air transport with fewer flight crew in large aircraft. The European Union Aviation Safety Agency (EASA) needs additional information about how this new concept of operations will affect safety with a focus on the analysis of human factors issues considering both normal operations and specific issues, such as sleep inertia, fatigue risk management, or pilot incapacitation.

Description of work

This document describes the planned experiments to be conducted in the eMCO-SiPO project. The experiments focus exclusively on eMCO operations and include nominal operations (Task 2), failure condition management (Task 3), sleep inertia (Task 4), and pilot fatigue and boredom (Task 6). The document first provides an overview of the general setup of each single experiment before providing details of the planned schedule. To increase the participation rate among CAT pilots and reduce travel efforts, the Task 2 and 3 experiments will be combined as well as the Task 4 and 6 experiments. This document describes the test sequence and provides all relevant information on planned analysis methods, such as debrief interviews and questionnaires.

Application

This document will feed into the final report generated in Task 9. In addition to that it will serve as a basis for the conduction of the simulator experiments for Task 2, 3, 4, and 6.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
A/C	Aircraft
AED	Automated Emergency Descent
AFC	Advanced Future Cabin
AVES	Air VEhicle Simulator
CAT	Commercial Air Transport
CAT	Commercial Air Transport
CBA	Cost Benefit Analysis
ConOps	Concept of Operations
CPT	Captain
CRM	Crew Resource Management
DBL	Deep Blue
DLR	German Aerospace Centre
DLR-FL	DLR Institute of Flight Guidance
DLR-FT	DLR Institute of Flight Systems
DLR-ME	DLR Institute of Aviation and Space Medicine
EASA	European Union Aviation Safety Agency
EFB	Electronic Flight Bag, Electronic Flight Bag
eMCO	Extended Minimum Crew Operations
FFS	Full Flight Simulator
FMGC	Flight Management Guidance Computer
FO	First Officer
HF	Human Factors
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation [UN]
IOS	Instructor Operator Station
ISA	Instantaneous Self Assessment
LOFT	Line Oriented Flight Training
NCO	Normal Crew Operations
NLR	Royal Netherlands Aerospace Centre (Dutch: Koninklijk Nederlands Lucht- en Ruimtevaartcentrum)
OEM	Original Equipment Manufacturer
PF	Pilot Flying
PM	Pilot Monitoring
PR	Pilot Resting
RTLX	Raw NASA TLX
SA	Situational Awareness
SiPO	Single Pilot Operations

SWAT	Subjective Workload Assessment Technique

1. Context

1.1 Background

Due to the ongoing developments in technology, automation and autonomous unmanned aircraft, there is an interest and desire to explore whether it is feasible to operate commercial air transport (CAT) with reduced flight crews in large aeroplanes. This feasibility is considered from both the safety as well as efficiency perspectives.

EASA was approached by aircraft manufacturers regarding the regulatory and safety aspects of such new concept of operations (CONOPs). Two specific CONOPs were identified:

- Extended Minimum-Crew Operations (eMCOs) are defined as operations where the flight time is extended by means of rest in flight with the minimum flight crew. It is achieved by allowing operations with one pilot at the controls during the cruise flight phase; however, offering an equivalent overall level of safety through compensation means (e.g. ground assistance, advanced cockpit design with workload alleviation means, pilot incapacitation detection, etc.). It is, in particular, relevant to large aeroplanes operated in CAT operations, for which no fewer than two flight crew members are currently required as per the Air Operations Regulation.
- Single-Pilot Operations (SiPOs) are defined as end-to-end single-pilot operations. Annex III (PART-ORO) ”Organisation requirements for air operations” to the Air Operations Regulation already foresees conditions and limitations under which these types of operations are allowed. In the future, it is expected that these conditions and limitations will need to evolve in order to extend single-pilot operations to large aeroplanes, provided that compensation means (e.g. ground assistance, advanced cockpit design with workload alleviation means, capability to cope with pilot incapacitation, etc.) are in place in order to provide for an overall level of safety equivalent to today’s two-pilot operations.

1.2 Scope of the document

This document describes the experimental test plan, i.e.,where, when and how the experiments in eMCO-SiPO will be performed. The experiments are performed in order to analyze concerns regarding the safety of eMCO with respect to workload, situational awareness, sleep inertia, fatigue and boredom. The experiments described in this document are aimed at the identification of possible safety hazards in normal and non-normal conditions, and to identify how eMCOaffects the alertness of the flight crew, including the effect of sleep inertia. Detailed scenario descriptions will be provided in a dedicated document. Figure 1 gives an overview of the contents of this document and the distribution of the content of the associated documents.

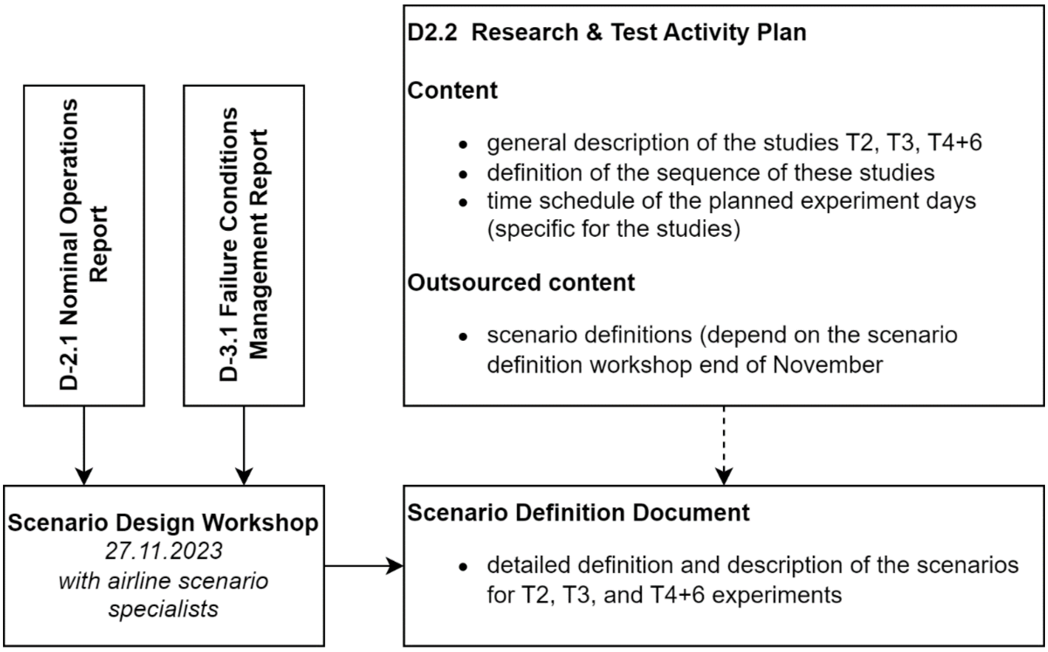

Figure 1: Scope of the document

2. General Information and Planning

It is planned to utilise different simulators for the nominal operations (task 2) and failure conditions management (task 3) experiments and the sleep inertia (task4) and pilot fatigue and boredom (task 6) experiments. The preferred platform for the task 2/ 3 experiments is a Level D Full Flight Simulator (FFS) at a major German airport due to the high representativeness of results obtained in a level-D and the reduced travel effort for participating pilots, thus potentially resulting in a higher participation rate among qualified pilots. The preferred platform for the task 4/6 experiments is in DLR's AVES simulator due to the overall scenario duration, increased observational possibilities, and higher controllability of the whole experimental setup. While the technical simulation capabilities of a Level D FFS are clearly defined [1], the section 2.1.2 describes AVES' capabilities and planned configuration for the task 4/6 experiments.

2.1 Description of the simulation facilities

2.1.1 Full Flight Simulator

It is planned to conduct the nominal operations and failure conditions management experiments as a combined study on a level D FFS located near a major airline hub for increased participant availability and expected increased participation rate. The targeted FFS will be a fully certified Airbus A320 simulator in airline use and will be rented by the eMCO-SiPO project via a third-party training company.

2.1.2 General overview of the AVES simulation facility

The DLR Institute of Flight Systems operates the Air VEhicle Simulator AVES (see *Figure 2*). The unique infrastructure of AVES has been built during the last years with the aim of providing a highly representative test platform for new cockpit functions and flight crew training research. AVES is modular in design and currently consists of one hexapod motion platform and two fixed-base platforms, each of which can be operated by placing one of four different cockpit cabins (cabs) on a platform. The cabs can be changed with a roll-in roll-out mechanism. A video demonstration of a cockpit exchange can be found on DLR's website.[1] Each simulation platform has its dedicated projection system with a wide field of view. The projection system used for the eMCO-SiPO experiments will have a field of view of 240° horizontally and 95° vertically with an auto-aligned 9-channel front projection. The current cabs comprise of replicas of an Airbus A320 cockpit, an Airbus Helicopters EC135 cockpit, a Falcon Dassault 2000LX cockpit, and the Advanced Future (passenger) Cabin (AFC). The cockpits represent the real counterparts to a very high degree and feature additional instructor operator stations from which the simulation can be controlled (IOS, Instructor Operator Station). Video cameras are installed at non-intrusive positions allowing the documentation of any flown simulation scenario. Footage recorded during the simulator experiment can be used during crew debrief directly after the experiment. For experiments where human factors are having an influence the video debriefing has shown to be a useful tool for helping to get into the discussion with a flight crew.

The motion platform is an electro pneumatic, six degrees of freedom motion system, whose motion cueing algorithms can be specifically tuned for a given task if needed.

[1] https://www.dlr.de/ft/desktopdefault.aspx/tabid-1387/1915_read-38610/

Figure 2: AVES Simulator. Left: The motion platform in the front and one of the fixed platforms in the back. Right: View inside of the Airbus A320 ATRA cockpit.

The corresponding simulation software (incl. flight dynamical models, system simulations, motion platform algorithm) is entirely developed at DLR to permit full access and flexibility in any investigation. On the one hand this offers the opportunity, for example, to simulate even other aircraft types as long as these can be operated using one of the available cockpits. On the other hand, new system ideas can be implemented easily (e.g. new assistance systems, more robust flight control).

During a simulator study, a typical lineup is for the instructor at the IOS to perform all simulator-specific tasks while monitoring the correct functioning of the simulator. Each simulator offers a dedicated control room outside the simulator that is typically staffed with the experiment lead and other observing scientists who may, among other things, perform ATC or cabin crew simulation using AVES' intercom functionality. The AVES building offers one meeting room that is typically used as a briefing room during experiment trials. In case of experiment video documentation any recorded footage can be accessed from inside the secure simulator network.

2.1.3 Planned AVES simulator setup for eMCO-SiPO studies

The planned experiments will be conducted using the Airbus A320 ATRA cockpit (see right part of *Figure 2*) either on the motion or the fixed base simulator platform. Motion simulation might be considered hindering for the sleep inertia & boredom study becauseexiting or entering the cockpit is not possible as long as the motion platform is active and the access bridge in the retracted position. Moving the bridge activates a safety horn that cannot be switched off and which might arouse participating pilots, thereby possibly having an effect on their sleep inertia and boredom. The detailed experimental planning in chapters 3 and 4 will specify whether the use of motion is considered necessary or hindering and therefore not planned.

The Airbus A320 ATRA cockpit replica will be used as a cockpit representative for current 4th generation CAT aircraft. The baseline for the simulation software will be derived from the available in-house developed Airbus A320 ATRA simulation that will be extended by relevant avionic and work load alleviation technologies of most modern CS-25 aircraft types as necessary for the respective study. The extensions will be performed in such a way, that the effects of such systems will be the same to the pilots as they are using the real aircraft. An example for such a modification might be the Automated Emergency Descent (AED) mode of Airbus A350 aircraft.

The baseline A320 ATRA simulation comprises of

- a flight dynamics model and flight controls model based on Airbus A320 data, partly derived from flight test data using DLR's test aircraft A320 ATRA,
- a Flight Management and Guidance Computer (FMGC) simulation,

- the simulation of hydraulic, electrical, fuel and air conditioning systems based on Airbus A320,
- cockpit displays (PFD, ND, ECAM, ISIS, DCDU) based on Airbus A320 ceo
- two electronic flight bags (EFBs) mounted on the sliding window console of each pilot seat. The EFBs are Windows tablet computers and can be used for any kind of purpose.

The sleep inertia, pilot fatigue and boredom study will use AVES' build in data recording functionality to record all relevant simulation signals. AVES' video recording functionality will be used in accordance with the general data protection reglation on a study-specific basis. Any study specific hardware, software, or requirement will be covered in chapter 4 of this report.

2.1.4 Addressing possible concerns regarding the use of A320 simulators (AVES and FSS)

With its unique features described above (e.g. its flexibility and expandability) the AVES simulator has shown to be a valuable research tool in many EU, EASA and DLR internal research projects. However, only an Airbus A320 cockpit is available. This section addresses points of concern regarding the use of an A320, together with actions how these concerns will be mitigated during the planned simulator experiments.

The first and main concern is that the state of the art of the equipment and automation of eMCO-capable aircraft is not sufficiently represented by the Airbus A320 cockpit. A secondary concern is that the eMCO ConOps mainly targets long range cruise flights, whereas the Airbus A320 that is represented by both simulators, is an aircraft typical for medium range operations.[2] A minor concern might arise from the usage of an airline FFS. These concerns are mitigated by the following countermeasures described:

1. During the scenario design process care will be taken to only select system errors that are very comparable if not identical in their consequences and necessary processing and pilot workload between the simulators used and the targeted aircraft type (e.g. Airbus A350, Dassault Falcon X). For example, based on the aircraft documentation, one engine on fire seems to cause similar implications as well as necessary crew actions and might therefore be a good trigger to cause effects in the flight crew. The aim of the scenario design process is that, even when flown with an eMCO-capable future aircraft instead of an range-extended Airbus A320 a very comparable result should be obtained. Any remaining and not mitigated effects will be taken into account in the analysis of the experiments.
2. The pilot selection criteria will be chosen carefully. It is planned to select only pilots that have both a valid long range rating and flight experience as well as a valid Airbus A320 rating and flight experience. The former is to assure the crews operational long range flight experience with the associated problem solving and solution finding experience. The latter is to assure that, in case of a simulated system error, the crews are current in dealing with A320 specific aircraft system errors.
3. The scenario design will be focused to target the situational awareness (SA) and decision making abilities of participating crews. This means that the focus of the analysis is not on the system error itself, but system errors are only used to create targeted effects in the flight crew and to see how these will react under the given context.

2.2 Time Planning and Planned Sequence of Simulator Experiments

The following three simulator studies will be performed:

1. Nominal Operations study
2. Failure Conditions study

[2] Except for the relatively new Airbus A321XLR: https://aircraft.airbus.com/en/aircraft/a320/a321xlr

3. Sleep Inertia & Boredom study

These studies will be carried out in the sequence shown in Figure 3. The sleep inertia experiments are split into two parts to take care of the fact that participating pilots shall act as their own control group. The participants will experience the same scenario elements in both parts of the sleep inertia experiments, but one time with experiencing a prior resting phase and one time without a prior resting phase. Both parts of the sleep inertia experiment are planned the furthest apart to allow paticipants to forget about the exact details of the first part of the experiment while still fitting the seconds part of the experiment inside the planned project simulator time schedule. A further argumentation behind the splitting of the sleep inertia experiment and the decision for the self-contained control group is detailed in chapter 4.

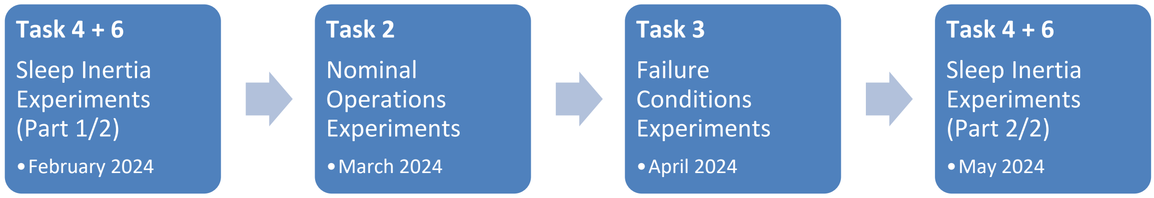

Figure 3 Sequence of simulator studies in the eMCO-SiPO project

Table 1: More detailed experiment planning

Study	Begin	End	Duration [working days]	Planned no. of study runs
Sleep Inertia Part 1	05.02.2024	01.03.2024	20 d	10[3]
Nominal Operations	04.03.2024	28.03.2024	19 d	10
Failure Conditions	02.04.2024	03.04.2024	24 d	10
Sleep Inertia Part 2	06.05.2024	31.05.2024	19 d	*10*[3]
			82 d	**40**

2.3 Overview of a General Experimental Run

Participants will be invited by sending out open invitations to several pilot communities. The invitees are asked to forward the invitation to fellow colleagues for increased dissimination. Additionally, pilot contacts provided by EASA, if any, will be invited. The invitation contains a link to a booking and survey system were participants can indicate their participation interest, provide their availability and fill out a demographic questionnaire. The demographic questionnaire collects information regarding the potential participants' flying experience.

Participant selection will be done according to the experiment specific inclusion and exclusion criteria after a reasonable amount of possible participants have shown their interest. After participant selection, operationally relevant crews will be formed based on participants' rank, (flying) experience, and availability. Subjects will then be informed regarding their participation date and further sequence of actions.

[3] Participants of the sleep inertia experiments shall be the same in both parts of the experiment, so they can act as their own control group.

3. Nominal Operation and Failure Conditions Management Experiments (Task 2 + 3)

3.1 Scientific Background

Aircrafts involved in commercial air transport are invariably certified with a minimum crew of two pilots.[4] System design, operational procedures, certification- and training standards and flight duty times are based on this premise. However, continued technological developments in fields such as real-time human performance measurement are being implemented in other modes of transport. In aviation, advances have been made in the design, certification and operation of autonomous unmanned aircraft. These developments bear the potential for safety and efficiency gains that may be applied to reducing the number of pilots aboard CAT aircraft while maintaining the present level of safety. When regulatory, technical and operational requirements can be met, it may be feasible that, for limited periods of the flight initially, the aircraft is operated with one active pilot on the flight deck. [2]

Given the situation that an aircraft is in cruise flight and controlled by one pilot only, both under eMCO CONOPs, or when a complete flight is executed by one pilot under SiPO CONOPs, care needs to be taken that the flight will be executed at the same safety level as under the current conditions when flying with a crew of two pilots. However, when a pilot is controlling an aircraft alone, and there is no one in the near vicinity to offer support or to monitor this pilot, a number of events and situations are conceivable under which control may be limited or safety may be reduced. As such, solutions or mitigations are needed to ensure operations can be carried out at the same safely levels as under the current operations. [2]

Since the current operation is at an acceptable safety level, this will form the reference for assessment of impact on safety. Therefore, the project plans to describe the impact on regulation and safety resulting from the foreseen changes in relation to the current situation. [2] The experiments for Nominal Operations (Task 2) and Failure Conditions Management (Task 3) are planned to deliver qualitative insight for the effects of the change in ConOps from NCO to eMCO when no mitigating solutions (as proposed by the industry) are applied. The experiment planning as well as the later analysis will target:

- Changed mental workload and / or Situational Awareness (SA) for a pilot who, on their own, executes the work of two persons;
- The fact that there will be no more human cross checking as a means to spot pilot error at an early stage;
- Fatigue during flying. Since there will be just one pilot, the impact of fatigue may be bigger compared to the situation with two pilots. A fatigued pilot will always have to realise when they are becoming fatigued. There is no other pilot present to bring that to their attention or to take any action. What can be done to compensate for this change, i.e., how can the impact of fatigue be minimised?;
- If the resting pilot needs to take action, will there be solutions to deal with sleep inertia that may affect their effectiveness immediately after waking up? What is the duration of sleep inertia?
- Boredom while being alone in the cockpit. If there is no colleague to talk to, what can be done to stay alert, to stay in the loop, while at the same time not be mentally isolated from what goes on the cockpit? What can be done to make sure that the pilot stays in the loop and is not distracted from their flying task(s) due to boredom?

[4] In limited cases, e.g. small aircraft operations, existing Air Operations rules allow operations by a single pilot.

3.2 Primary Hypothesis

Compared to flights under the NCO ConOps, the application of eMCO ConOps shows negative effects on the flight crews’ situational awareness, their workload, error rate, and the quality of their decision making.

3.3 Intended Time Frame

The nominal operation and failure conditions management experiments (Task 2 and 3 experiments) are planned for March and April 2024 (cf. Figure 3).

3.4 Study Population, Inclusion Criteria, and Desired Crew Complement

The required inclusion criteria for participants are pilots in active duty with a valid Airbus A320 familiy type rating and a valid Airbus A350 rating. In order to be accepted, participants need to sign the written informed consent (incl. consent form for test subjects and the data protection regulation). To obtain a representative crew complement, crews will be formed from the pool of interested participants meeting the inclusion criteria with a crew complement of CPT and FO or SFO flying for the same operator. In the event that not enough crews can be formed with this complement, crew comprising of (S)FO and FO may be formed. This step would require additional care in the later analyses of results.

3.5 Subject Recruitment, Screening and Selection Procedures

Participants will be invited by sending out open invitations to several pilot communities. Interested pilots will be asked to fill out an online questionnaire regarding their flying experience and time availability. Based on this data, crews will be formed according to the criteria described in section 3.4 above. Crews will be informed about their acceptance to the experiment and the planned date. Approximately one week in advance of the experiment an online info session with the crew is planned where the crew will receive a training on the eMCO ConOps and supplemental study materials (handout of the eMCO concept as planned, consent form for test subjects, data protection regulation form).

3.6 General Study Design

The simulator experiments for task 2 and 3 will be performed according to the counterbalanced, within-subject and within-group design that is shown in Figure 4. In this design, the experiments of Task 2 and Task 3 are combined in such a way, that a flight crew performs both experiments for both tasks in one single visit at the flight crew training centre. Combining both experiments in one flight crew yields several benefits. For example, each flight crew can generate their own reference data, the available simulator time (which is charged per day) is better utilized, and the travel effort of flight crews is optimized. In an online info session preceeding each experiment flight crew is trained on the concept of eMCO with a video presentation and preceeding discussion. For the experiments participating crews will be randomly categorized into one of four groups. Each participating crew performs one nominal operations scenario and one failure conditions management scenario. The group the crew is categorized in determines the sequence of these scenarios and under which ConOps they are to be flown. A counterbalanced distribution is sought, but the exact distribution depends on the total number of available flight crews. Each crew provides its own reference data (the Normal Crew Operations (NCO) scenario) as well as results under eMCO and is comparable within-subject. It is assumed that due to the high training standardization within European airlines as well as carefully selected flight crews for the experiments these crews will perform in a comparable way and that their performance can be compared between NCO and eMCO within-group. That means, that the performance of the flight crew performing e.g. nominal operations under NCO will be compared to another flight crew’s performance of the nominal operations scenario under eMCO. The counterbalanced distribution is further used to identify effects of flight crew familiarization to the simulator. The simulator's motion platform will not be used because this restricts access to the simulator and prevents proper representation of scenarios where the eMCO needs to be aborted..

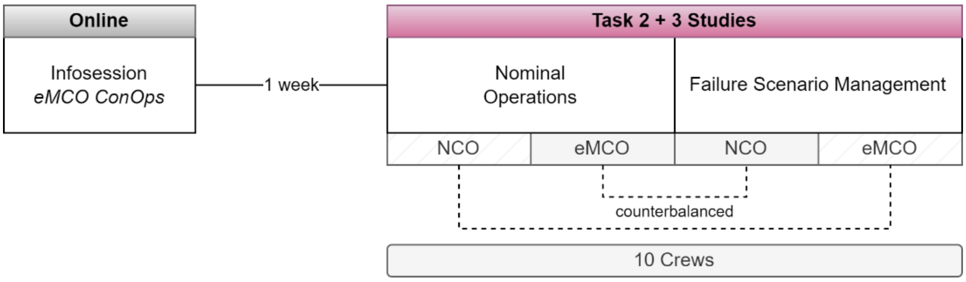

Figure 4: General study design as combined Task2/3 counterbalanced within-subject study

In all three studies the participants are expected to operate under eMCO. However, they have had no prior exposure to this concept of operations. Participating crews therefore need a minimum of training on this ConOps before flying eMCO scenarios in a simulator. Both to give participating crews enough study time to accommodate to the new ConOps as well as reducing necessary time on the experiment day, each crew will receive an online info session in which the crew will be introduced to the eMCO concept. The participants are first shown a video explaining the eMCO concept. Any upcoming participant questions will be answered in a subsequent discussion. The appointment is also used to inform the participants about the planned schedule for the test day as well as to exchange any necessary documents (e.g. informed consent).

The eMCO training will be based on data provided by EASA, but adapted to the AVES (e.g. meeting room as the resting area, detailed eMCO abortion criteria, etc.). An accompanying handout will be given to the crews as a reminder for self study until the day of the experiment.

3.7 Detailed Study Design

For the detailed planning two options exist to accomodate for participant availability and to increase the participation rate. The options are: A) whole day experiment from morning to evening, B) a split two day experiment. The sequence of the whole experiment setup is not changed between the options. This section will first describe option A. Option B will be explained thereafter.

The counterbalanced within-subject within-group study design mentioned in the section above is detailed in Figure 5. Crews will be assigned evenly to one of the four groups A1, A2, B1, and B2. The groups determine in which sequence crews will experience the nominal operations (Task 2) and failure condition management scenarios (Task 3) and under which concept of operations. The overall program (arrival, introduction, simulator familiarization, lunch break and wrap-up, is identical for crews in all groups.

- Crews in the A groups are first exposed to the nonimal operations scenario and thereafter to the failure conditions management scenario.
- Crews in the B groups are first exposed to the failure conditions management scenario and thereafter to the nominal conditions scenario.
- Crews in the 1 groups fly the first scenario under NCO and the second scenario under eMCO.
- Crews in the 2 groups fly the first scenario under eMCO and the second scenario under NCO.

Figure 6 gives a more detailed view of the study design overview. The corresponding schedule is also given in Table 2. In the following, the experiment day is exemplarily described for an A2 crew.

After an introduction to the team of researchers the crew receives a simulator briefing and thereafter a general safety briefing. The crew is then guided to the simulator to fly a short familiarization scenario in order to getting used to the look and feel of the simulator The familiarization phase will be finished at 10:30. The crew then is guided back to the meeting room to receive their briefing presentation and documents for the first scenario flight. In case of an A2 crew this is the nominal operations scenario. Both scenario flights are designed in the style of LOFT flights (Line Oriented Flight Training, LOFT). Total briefing time is planned to be 30 minutes. After the crew has boarded the simulator the scenario flight begins at 11:15. According to simulated time, the scenarios will begin 15 flight minutes before the planned beginning of the eMCO segment. The crew is expected to perform their eMCO segment briefing, after which the then PR will leave the flight deck. The PR is asked to return to the meeting room and stay there. He can pass the time on his own discretion, but according to eMCO ConOps is tasked to monitor any command to return to the flight deck in case of an aborted eMCO segment.

At 12:15, after 45 minutes into the eMCO segment, the scenario event will be triggered (e.g. unruly passenger, medical emergency, deteriorating weather with large scale effects). This event is expected to cause the PF to abort the eMCO segment and call the PR back to the flight deck. The PR receives the PF's call in the meeting room and return to the simulator. The current planning allots the crew 45 minutes for the handling of the event and their final decision on how to proceed the flight. Additional 15 minutes are planned as time buffer to end the simulator scenario. During the scenario the participants will be prompted to rate their workload in the cockpit-installed EFBs at or near key events (see 3.9.2.1 *Instantaneous Self Assessment (ISA)*). Depending on time the crew may finish the scenario flight with a landing, but is not required to. At 13:15 the scenario is ended. The participants are asked to rate their overall workload using the NASA RTLX (see 3.9.3.1 *NASA Raw Task Load Index (RTLX)*) after which they are guided to the meeting room for an extended 45 minute debriefing. During the debriefing the scenario's key elements and decisions are discussed with the crew using a playback of the video recording. This concludes the first scenario.

Before the second scenario a one hour lunch break is planned with catering served in the meeting room. Part of the lunch time can also be used as a buffer in case time is short. The second scenario is planned to begin at 15:00 with an identical sequence (briefing, self-briefing, boarding, scenario flight, debriefing) except that this scenario now targets the failure conditions management (Task 3) and is flown under NCO. For comparability reasons NCO scenarios will be of identical duration to the eMCO flight, meaning the crew will fly for one hour before the event is triggered (as eMCO flights will fly for 15 minutes in NCO and then 45 minutes in eMCO). Consequently, at 16:45 the failure condition will be triggered. The crew is then given 45 minutes time with an additional 15 minutes buffer for their problem solving and decision making. Once the final decision has been made, the simulation will be stopped. As with the first scenario, a 45 minute video debriefing session in the meeting room concludes the second scenario (Task 3 experiment). The experiment day ends with a 30 minute wrap-up and departure at 19:00.

Figure 6 also depicts the combinations of ConOps and Tasks. For example, crews in group A1 fly the nominal operations scenario under NCO (not eMCO as A2 crews) and the second experiment under eMCO (not NCO as A2 crews). For crews in groups B1 and B2 the sequence of nominal operations and failure condition management scenarios are swapped in comparison to A1 and A2 group crews.

The experiment can be split into two days, as exemplarily shown in Figure 7. The crew will then fly the first scenario in the afternoon (to accommodate for their travel), and the second scenario the following morning. Although this means that the simulator time cannot be used as efficient as with the one day experiment setup, the two day setup would still be beneficial, if this is the only possibility for a crew to participate.

Table 2: Schedule for combined Task 2+3 experiments

Schedule	Group A1	Group A2	Group B1	Group B2
09:00	Arrival			
09:15	Introduction			
09:30	Simulator Familiarization			
10:30	Preparation for 1st scenario (incl. briefing presentation, self briefing, boarding)			

11:15	Nominal Operations + NCO	Nominal Operations + eMCO	Failure Condition + NCO	Failure Condition + eMCO
13:15	Debriefing 1st scenario			
14:00	Lunch Break			
15:00	Preparation for 2nd scenario (incl. briefing presentation, self briefing, boarding)			
15:45	Failure Condition + eMCO	Failure Condition + NCO	Nominal Operations + eMCO	Nominal Operations + NCO
17:45	Debriefing 2nd scenario			
18:30	Wrap-up and departure			

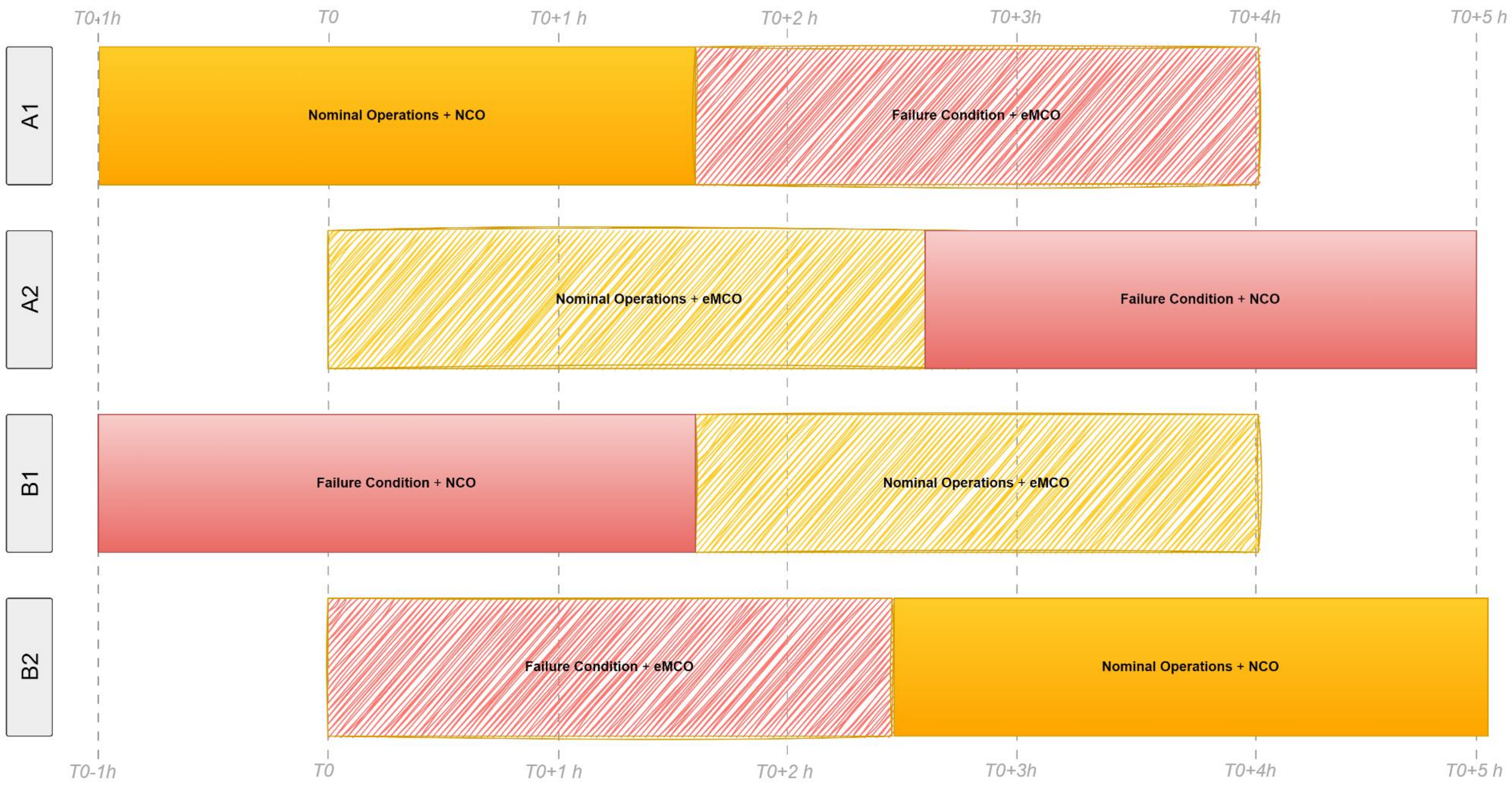

Figure 5: Study design overview

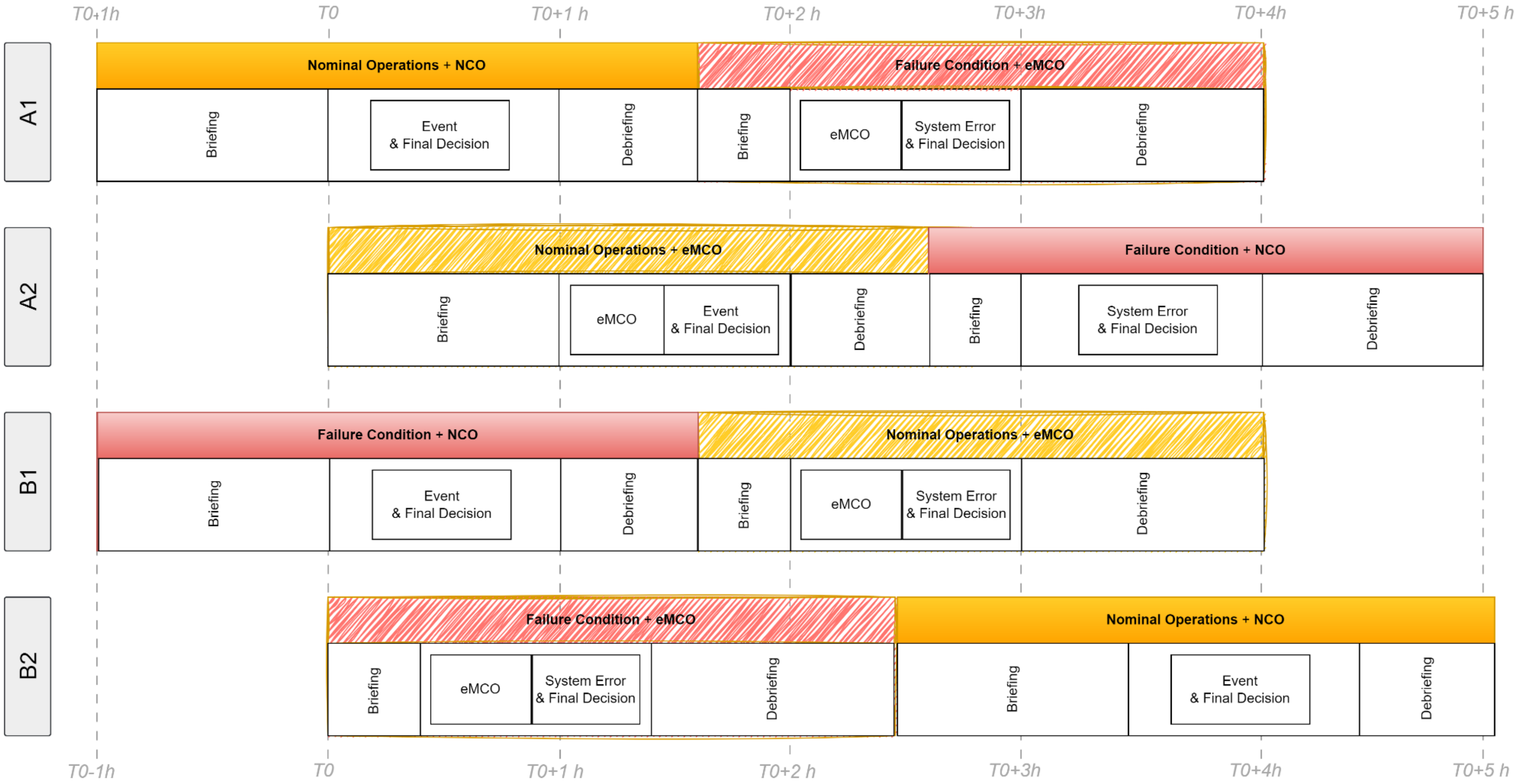

Figure 6: More detailed study design

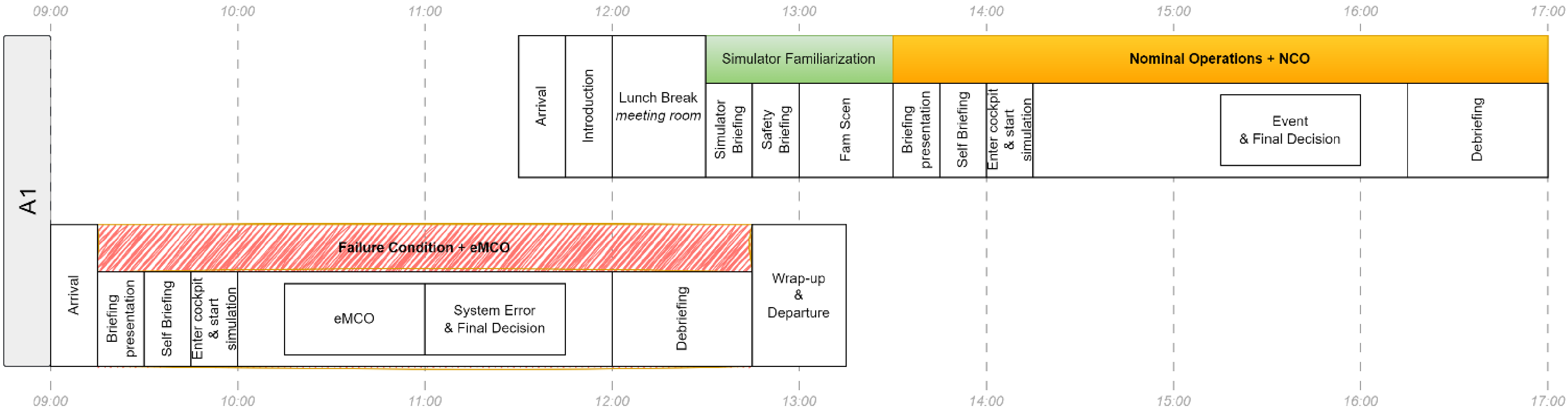

Figure 7: Alternative 2 day example

3.8 Definition Simulator Scenarios

The detailed scenarios will be described in the *eMCO-SiPO Scenario Definition Document [3]*. The scenarios were developed in a workshop with CAT simulator scenario developers from a major European airline with medium and long haul flight experience.

3.9 Measurement Techniques and Debriefing

In accordance with [4] a combination of measurement techniques were chosen to cover multiple estimates of workload per scenario and ConOps. Once started, a running scenario should not be paused for a rating, which limits the use of subjective measurements to one-dimensional rating scales. After each scenario time would permit the use of a multidimensional workload rating tool. The *Instantaneuos Self Assessment* (ISA) was chosen as measurement technique during the running scenario together with a NASA Raw Task Load Index (NASA RTLX) to assess overall workload after the end of each scenario. After each scenario a detailed video debriefing is performed with the crew.

During and after the experiment the participants' workload will be evaluated and their situational awareness will be evaluated in the video debriefing with the crew. Video debriefing was selected for situational awarenss assessment because there is no non-intrusive way to measure SA objectively during the experiment and the sensitivity of subjective SA ratings is low. Subjects may not be able to precisely rate their poor SA as they may not realize that they have inadequate SA from the beginning [5].

The following sections will explain the selected measurement techniques in more detail.

3.9.1 Measurements before the experiments

A demographic questionnaire ist used to collect information on the participants' educational background, any secondary airline positions (e.g. involved in training) and their flying experience. The used questionnaire is contained in Appendix A.1 *Demographic Questionnaire*.

3.9.2 Measurements during the experiments

3.9.2.1 Instantaneous Self Assessment (ISA)

For the ISA measurement participants are asked to provide an instantaneous self-assessment of their subjective workload on a five point discrete scale from "1" (very low) to "5" (very high) [6]. The participants will give their rating by pressing one of five buttons whenever they see a visual attention getter on the rating device. The visual attention getter is activated at the time the participants are expected to give their rating and stays on for 60 seconds or until the rating was given. After 60 seconds the rating device is deactivated until the next activation. The implementation of the ISA depends on the available space in the particular FSS. If EFBs are installed, the prompt and rating will have to be given verbally. If there are no pre-installed EFBs, the rating device will be displayed on tablet computers that will be fixed on the sliding window frame. The participants' rating as well as replay time (time from activation of the visual attention getter) are saved. Participants are briefed prior to the experiment, that the ISA rating is a secondary task that may be omitted when they have no time in their primary task for this. The times at which the pilots are prompted depends on the particular scenario definition and therefore will be defined in the scenario description document. It is planned to prompt the participants several times over the course of the scenarios at measureable events (e.g. reaching/leaving a certain altitude, crossing certain waypoints, or at or near scenario key events) that are comparable across the combinations spanned by scenario type and ConOps. Measurements will be compared between scenarios (within-subject) and ConOps (within-group) after the completion of the trial. The hypothesis is that participants give higher workload ratings under eMCO compared to NCO.

3.9.2.2 Video/Audio Recording

During the scenario flights the flight deck will be recorded by a video camera that is attached to the cockpit's rear wall and captures the whole cockpit area. The sound will be recorded directly from the participants' headsets (incl. intercom, ATC, and simulator operator). Additionally, for the AVES experiments, all cockpit displays are screengrabbed and all streams (video and audio) will be combined into one synchronized video file. This file will also be used during the participant video debriefing after the experiment. An example configuration from an earlier study is depicted in Figure 8. For the experiments conducted on the FSS additional display recordings will be set up using external cameras when necessary. This will be decided during the final FSS-specific experiment preparation.

Figure 8: Example configuration of the synchronized video file incl. cockpit rear camera, PFD, ND, and ECAM

3.9.2.3 Expert Observation

An expert with operational knowledge will monitor the scenario flights and note timestamps of key events like crew discussions regarding SA topics, decision making, or deviation of procedures where made. These timestamps will be used to reanalyze the events with the crew during the video debriefing .

3.9.3 Measurements after the experiment

3.9.3.1 NASA Raw Task Load Index (RTLX)

The Raw NASA TLX (RTLX) was chosen to measure the participants' total workload after the completion of each scenario. The RTLX differs from the original TLX: It is easier to fill out by the participants as they only have to rate their workload in the six dimensions without the following decision on the importance of these scales, thereby reducing the time needed by the participants to give the rating. Despite the simplification, the RTLX has shown to "be almost equivalent to the original TLX scale… with far less time involved for analysis". [4] The RTLX was chosen over the Subjective Workload Assessment Technique (SWAT) that could have been an alternative to the RTLX, but the former has not shown to be especially sensitive to an increase in workload during the cruise segment of a high workload flight for measuring transport pilot workload. Additionally, the NASA TLX results were found to be stable for repeated test whereas this was not the case for SWAT ratings. [7]

Due to the low number of total samples (n=20 pilots, 10 crews) sensitivity and repeatability are important to the experiment. The NASA RTLX will be shown and filled out on the EFBs in the simulator.

3.9.3.2 Video debriefing and Simulator Logging Data

Participation is only possible with a positive informed consent regarding the data and video recording. The recorded video is used in a debriefing interview session in the meeting room where key events of the scenario are discussed with the crew using a playback of the previously recorded camera footage. The debriefing interview session may be supplemented by extracts of simulator logging data where applicable.

3.9.3.3 Perceived Simulation Quality Questionnaire

This questionnaire is collected to gain ratings of the participants' perceived simulation quality, simulator and scenario representativeness. The questionnaire is contained in Appendix A.3 *Perceived Simulation Quality Questionnaire*.

4. Sleep Inertia, Pilot Fatigue and Boredom Experiments (Task 4 + 6)

A central question for the safety of eMCOs is what happens if an event occurs that forces the abortion of the eMCO segment (i.e., incapacitation of PF, system error) and the PR needs to take over, while still in a state of sleep inertia. Sleep inertia refers to a transient state of 'grogginess' and disorientation immediately after waking up, during which cognitive performance is impaired [8]. To determine the operational safety of eMCOs, the ability of a pilot to operate an aircraft while cognitively impaired due to sleep inertia needs to be investigated. Also, the effects of pilot fatigue and boredom will be investigated in these experiments.

4.1 General Study Design

The general study design (shown in Figure 9) is a counterbalanced, within-subject design that includes two visits in randomized order to the flight simulator center. Each visit includes one test day, preceded by an overnight stay to facilitate early-morning arrival at the flight simulator site. Each test day lasts 5-7 hours and includes of a 2-hr briefing and a 1.5-hr to 3.5-hr test session, during which participants perform an eMCO segment in the flight simulator, that either ends as scheduled (i.e., PR shows no sleep inertia) or is aborted due to a system error that requires immediate action by the PR (i.e., PR shows potential sleep inertia). The order of the eMCO segments (not aborted vs. aborted) will be counterbalanced (i.e., 50% of participants will experience a non-aborted eMCO segment during their first visit, the other 50% will experience an aborted eMCO segment). The two visits will be separated by approximately 8-12 weeks, to accommodate pilots' flight schedules and increase participation rate. No additional visits are anticipated.

Participants will not be informed a-priori about the possible abortion of eMCO segments nor about the focus of the study on the effects of sleep inertia on flight simulator performance. There will be a written debriefing at the very end of the study (i.e., when data collection of all participants is finished), sent via email to participants.

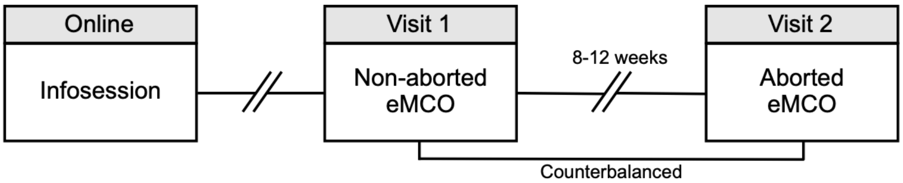

Figure 9. General Study Design

4.2 Detailed Study Design

Participants (N = 2 pilots per test day) arrive at 3:00 in the morning at the flight simulator center and participate in a 2-hr briefing, including a training session in the flight simulator. After the briefing, the sleep-measuring equipment (polysomnography, PSG) is attached to the PR (~ 30 minutes). At 6:00, the test session starts, with both pilots A and B managing the start/departure of the aircraft. At 6:30, the eMCO segment starts, allowing Pilot B to assume the role of PR, while Pilot A continues in his/her role of PF. These roles will be randomly assigned during the first visit and remain the same for both visits.

In case of an aborted eMCO, the segment is interrupted at 7:00 (30 min after the segment started) due to a system error, that requires immediate action by the PR. After the system error has been dealt with, the testing session is over and participants get a de-briefing, after which they are free to leave (Figure 10).

In case of a non-aborted eMCO, the segment ends according to procedure without interruptions after 2.5 hours and the PR assumes his/her regular duties again. At 9:30 (30 min after the end of the eMCO segment), the same system error as in the aborted-scenario occurs, also requiring immediate action by Pilot B (who assumed the role of PR during the eMCO segment). After the system error has been dealt with, the testing session is over and participants get a de-briefing, after which they are free to leave (Figure 10).

Throughout the test session in the flight simulator, participants rate their subjective fatigue and sleepiness at several intervals, e.g., start and end of the test session, start and end of the eMCO segment, and, for PF only, at 30-min intervals during the eMCO segment.

Schedule:
3:00 Arrival
3:15 Briefing (incl. training session in the flight simulator)
5:15 Attachment of sleep-measuring equipment
5:45 Preparations in the flight simulator (e.g., taking seats, starting the system)
6:00 Test session starts
6:30 eMCO segment starts
In case of aborted eMCO segment:
7:00 System error occurs
~7:15: Test session ends, debriefing
In case of non-aborted eCMO segment:
9:00 Segment ends regularly without interruption
9:30 System error occurs
~9:45: Test session ends, debriefing

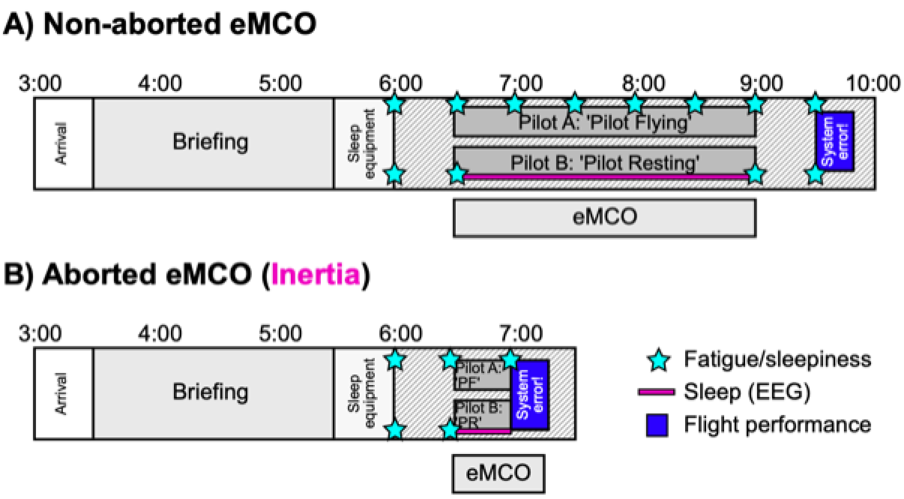

Figure 10: Examination protocol with timing of non-aborted (panel A) and aborted (panel B) eMCO segments

4.3 Simulator Familiarization

4.3.1 Simulator Briefing

Although AVES is designed for highest fidelity it is a highly flexible research simulator that is not limited to simulating one single aircraft. For example, the AVES Airbus A320 ATRA cockpit features active sidesticks as main control inceptors. For the simulation these are set up in a passive force/deflection/damping mode to resemble the Airbus sidestick feel, but are reported to still feel slightly different. One other example is the touch and feel of the replica buttons and switches that, although being highest quality, slightly differs to their original counterparts. Known differences to the real aircraft or Level D simulators that the participants are used to are discussed with them during a class-room presentation. The participants are given a further possibility to familiarize themselves with the AVES A320 ATRA simulation during the subsequent familiarization flight.

4.3.2 Safety Briefing

As per safety regulations each occupant of the AVES simulator must be given a safety briefing. The intention of this briefing is to inform the participants about the required and expected behavior, e.g. in case of an evacuation due to fire. This safety briefing consists of a theoratical part in form of a presentation in the meeting room and a practical demonstration of the safety devices (e.g. emergency stop buttons, fire extinguishers) inside the simulator. After the practical part of the safety briefing is concluded the familarization flight begins.

4.3.3 Familiarization Flights

To account for AVES' differences to the real aircraft or A320-type Level D simulators, participating pilots are given the opportunity to familiarize themselves to AVES' look and feel in a familiarization scenario. The intention of this scenario is to familiarize the flight crew with the look, feel, and operation of the AVES A320 ATRA with some basic flying and system handling tasks and without giving away hints about events of the upcoming experiment scenario. The familiarization scenario will be tailored to the specific study and typically contains manual flying tasks and system handling tasks, e.g. in form of an extended traffic pattern that is flown manually in the start and landing phase while using automation during the level flight segments. The crew is asked to work according to their normal CRM with the roles of PF and PM.

4.4 Pilot Performance

Pilot performance will be assessed measuring the time it takes to solve the simulated system error (including executing multiple action items) and success in actually solving the error (yes/partial/no) (Figure 11). During the eMCO segment, the PR is resting/sleeping, while the PF is in charge of operating the aircraft. Approximately 23 min after the start of the eMCO segment, weather conditions worsen, requiring the PF to alert the PR (as per eMCO guidelines), using standardized verbal commands (if the PF has not alerted the PR within 2 min, the PF will be notified by the principal investigator to do so). From the onset of the PF's verbal commands, 5 min will elapse after which the system error occurs, meaning the PR can be awake for a maximum of 5 min at the time of the system error. The rationale for this design is: the change in weather conditions makes sure that the PR is already alerted but still in a state of sleep inertia at the time of the system error. Otherwise, the possibility exists that the PF starts solving the system error on his/her own, while the PR is still in the process of waking up. In order to solve the system error, the PR needs to execute a series of action items as per handbook instructions, for each of which reaction time to complete will be measured (RT1, RT2, RTn in Figure 11). The time until the system error is successfully resolved (i.e., successful execution of the last action item, $RT_{overall}$ in Figure 11) will also be assessed. Partial failure of the PR to solve the error will be determined by the PF taking over any of the action items and complete failure if the system error persists.

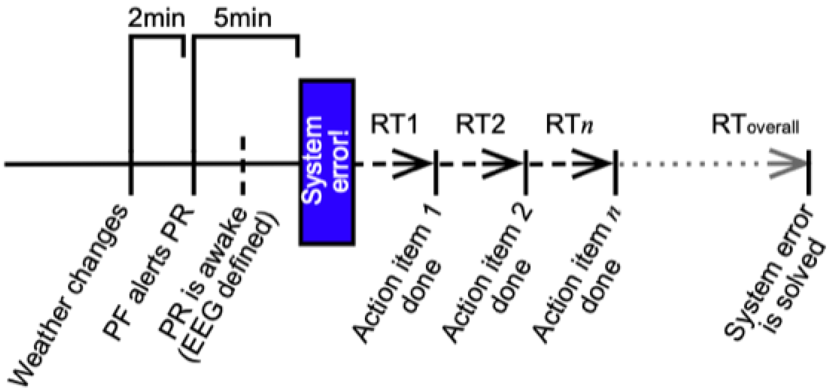

Figure 11: Assessment of flight performance

Sleep will be assessed using the Dreem2 headband, a portable, lightweight device that is worn around the head (https://dreem.com/), measuring EEG via 5 sensors. The headband is a validated alternative to assessing sleep by polysomnography, it requires no attachment of electrodes to the scalp and has no cables, and is thus well-suited to not interfere with pilots' flight simulator performance in a cockpit environment. In case of malfunction or technical issues with the Dreem2 headband, sleep assessment will default back to polysomnography using portable devices. Sleep will be measured during eMCO segments (both aborted and non-aborted segments) of the Pilot Resting, to record sleep duration, quality, and structure (i.e., sleep stages). Sleep stages are scored visually in 30-s epochs by a trained somnologist, according to the International Criteria [9]. Fatigue will be measured using the Samn-Perelli fatigue scale [10]. Boredom is likely to be measured using a self-assessment scale [11].

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Annex A Task 2+3 Questionnaires

A.1 Demographic Questionnaire

* **Flying Experience (present)**

This question is mandatory. Please complete all parts.

Operator
A/C type
A/C model
Years on model
Hours on model (approx.)
Rank

Operator is only used for crew matching. Other flying experience data is used for statistical analysis.

Other previous experience

Answer if you think this experience imparted important knowledge, skills or attitudes for the rest of your career; excluding General Aviation

General Aviation experience

If so, please provide details such as type of general aviation activity, professional level, timeframe, etc.

Secondary airline position

Other official activities, e.g. instruction, safety, engineering)

Engineering / IT experience

Background / education or other experience in engineering or IT / computer systems

A.2 Self-Rating Questionnaires

A.2.1 NASA RTLX

*
Mental demand
How much mental demand and perceptual activity was required (i.e. thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Please click and drag the slider handles to enter your answer.

low high

*
Physical demand
How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Please click and drag the slider handles to enter your answer.

low high

*
Temporal demand
How much time pressure did you feel due to the rate or pace at which the scenario elements occurred? Was the pace slow and leisurely, or rapid and frantic?

Please click and drag the slider handles to enter your answer.

low high

*
Performance
How successful did you think you were in accomplishing the goals of the scenario? How satisfied were you with your performance in accomplishing these goals?

Please click and drag the slider handles to enter your answer.

low high

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

Please click and drag the slider handles to enter your answer.

low high

*
Frustration level
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Please click and drag the slider handles to enter your answer.

low high

A.2.2 SART

*
Complexity of Situation
How complicated was the situation? Was it complex with many interrelated components (high) or was it simple and straightforward (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Instability of Situation
How changeable was the situation? Was the situation highly unstable and likely to change suddenly (high), or was it very stable and straightforward (low)?

Please click and drag the slider handles to enter your answer.

0
low high

*
Variability of Situation
How many variables were changing in the situation? Were there a large number of factors varying (high) or were there very few variables changing (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Arousal
How aroused were you in the situation? Were you alert and ready for activity (high) or did you have a low degree of alertness (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Concentration of Attention
How much were you concentrating on the situation? Were you bringing all your thoughts to bear (high) or was your attention elsewhere (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Division of Attention
How much was your attention divided in the situation? Were you concentrating on many aspects of the situation (high) or focused on only one (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Spare Mental Capacity
How much mental capacity did you have to spare in the situation? Did you have sufficient capacity to attend to many variables (high) or nothing to spare at all (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Information Quantity
How much information did you gain about the situation? Did you receive and understood a great deal of knowledge (high) or very little (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Information Quality
How good was the information you have gained about the situation? Was the knowledge communicated very useful (high) or is it a new situation (low)?

Please click and drag the slider handles to enter your answer.

low high

*
Familiarity with Situation
How familiar were you with the situation? Did you have a great deal of relevant experience (high) or was it a new situation (low)?

Please click and drag the slider handles to enter your answer.

low high

A.3 Perceived Simulation Quality Questionnaire

*

AVES cockpit
To what extent is the AVES simulator cockpit a complete representation of the Airbus A320 cockpit environment (i.e. switches, displays, panels, controls, visibility, etc.)?

This question is mandatory. Please complete all parts.
Please click and drag the slider handles to enter your answer.

no distinct similarities — completely accurate

*

AVES software
In your experience, did the simulation software accurately model an Airbus A320 aircraft and systems (i.e. controllability, system status, accurate values, etc.)?

This question is mandatory. Please complete all parts.
Please click and drag the slider handles to enter your answer.

no distinct similarities — completely accurate

*

Scenario setting
How did you experience the location, routing and circumstances of the scenario as comparable to a real-life operational situation (i.e. weather, fuel, etc.)?

This question is mandatory. Please complete all parts.
Please click and drag the slider handles to enter your answer.

practically impossible — completely realistic

*

Scenario events
How did you experience the events which unfolded during the scenario as compared to real-life situations you know of or have experienced (i.e. problems, communications, decisions, etc.)?

This question is mandatory. Please complete all parts.
Please click and drag the slider handles to enter your answer.

practically impossible — completely realistic

*

Overall simulator experience
In general, to what extent were you regularly confronted with unrealism, or did you feel continuously engaged within the scenario during this simulation?

This question is mandatory. Please complete all parts.
Please click and drag the slider handles to enter your answer.

very distracting — completely immersed

European Union Aviation Safety Agency

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