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D-2.1 REPORT ON NOMINAL OPERATIONS

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

An Agency of the European Union

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SUMMARY

This report describes the most relevant hazards arising from the eMCO operations. These hazards were identified during a literature survey and the CAT pilot workshop conducted in June 2023 . In addition to potential workload issues resulting from the fact that only one crew member is on duty during the eMCO phase, a special focus is put on human factors. Different scenario events are listed and related to the identified hazards. This report is limited to normal operations, i.e. it is assumed that no sytem failures occur during the eMCO segment. However external hazards, such as unruly passengers or medical emergencies, are considered. Finally a selection of the most relevant events based on the results of the CAT pilot workshop conducted in June 2023 is presented. These events will serve as the basis for the detailed scenario design. The scenarios will then be used for the normal operation experiments planned for beginning of 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. EASA needs additional information about how this new concept of operations will affect safety. The eMCO-SiPO project will assess the issues and the feasibility of the implementation of eMCOs in the EU regulatory framework

Description of work

This document (D2.1 Report on Nominal Operation) has been prepared to sum up the initial results obtained in Task 2 Nominal Operations. Based on the operational knowledge existing within the consortium, hazards specific to the Extended Minimum Crew Operation as well as related relevant scenarios and/or events have been identified. This list of hazards and scenarios has been discussed and completed during a dedicated workshop with airline pilots and pilot association representatives. In addition to that, the task of the workshop was to rank the scenarios in terms of their relevance.
This document includes the interpretation of the workshop results. In Section 3 the general hazards related to eMCO are presented and explained. In Section 4 relevant scenarios and events are described and their main elements are related to each hazard. Finally, in Section 5, a scenario overview is presented.

Application

This document will feed into the final report generated in Task 9. In addition to that it will serve as a basis to select and design a detailed scenario for the upcoming simulator experiments planned in Task 2.

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ABBREVIATIONS

ACRONYM	DESCRIPTION
A/C	Aircraft
A/C	Aircraft
AGL	Above Ground Level
AOC	Airline Operation Centers
ATC	Air Traffic Control
ATPL	Airline Transport Pilot License
CAT	Commercial Air Transport
CBA	Cost Benefit Analysis
CONOPs	Concept of Operations
CPDLC	Controller-Pilot Data Link Communications
DBL	Deep Blue
DLR	German Aerospace Center (German: Deutsches Zentrum für Luft- und Raumfahrt)
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
ECAM	Electronic Centralized Aircraft Monitor
EICAS	Engine Indication and Crew Alerting System
eMCO	Extended Minimum Crew Operations
ETOPS	Extended Twin-Engine Operations
FL	Flight Level
FMA	Flight Mode Annunciator
FMS	Flight Management System
FO	First Officer
FORDEC	Facts, Options, Risks & Benefits, Decision, Execution, Check
ft	feet
FTL	Flight Time Limitations
GPS	Global Positioning System
HF	Human Factors
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation [UN]
LH	Lefthand
MPL	Multi-Crew Pilot License
NCO	Normal Crew Operation
NLR	Royal Netherlands Aerospace Centre (Dutch: Koninklijk Nederlands Lucht- en Ruimtevaartcentrum)

NOTAMS	Notice To Airmen
OEM	Original Equipment Manufacturer
PF	Pilot Flying
PR	Pilot Resting
SiPO	Single Pilot Operations
TEM	Threat and Error Management
XPDR	Transponder

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 includes the findings obtained by a literature review and by a workshop conducted with CAT pilots in June 2023. The scope of the document is limited to normal operation, i.e. no system failure is considered during the eMCO segment. Specific hazards related to eMCO in the presence of sytem failures will be address in a separate document.

2. CAT Pilot Workshop

In June 2023 a workshop with Commercial Air Transport pilots was conducted in Amsterdam. Six pilots from Western-European airlines took part in the workshop. All participants were representatives of European pilot unions. The main focus of the workshop was to

- identifiy all relevant hazards arising from eMCO,
- complete the list of scenarios which are relevant in terms of their safety impact in eMCO,
- select the most relevant scenarios or scenario element w.r.t. to their safety impact.

The workshop considered nominal operations as well as failure managent during eMCO. This report focusses on nominal operation events, whereas the system failure events will be addressed in Deliverable 3.

During the workshop extensive notes were taken. Based on these notes a detailed summary is provided in Annex A .

3. General Hazard Description

3.1 Lack of Error Management

The current concept of Threat and Error Mangement (TEM) is based on cross-checks performed between the two crew members. This concept is essential to detect pilot errors in an early stage. During the eMCO Phase there is no Pilot Monitoring (PM) leading to an increased number of pilot errors that are not caught by the other crew member. Assuming that the autoflight system is always engaged during the eMCO Phase, pilot errors during cruise in normal operation might result in

- Deviation from the planned airspeed as well as from the lateral and vertical flight path due to wrong setpoints for the autoflight sytem
- Activation of wrong autoflight modes

Based on pilot experience collected during the CAT workshop it happens multiple times a day that pilot errors are caught by cross-checks. Specific examples of pilot errors that occur in real operations are:

- Only partial activation of “Direct To” in Flight Management System resulting in deviation from lateral flight path
- Forgotten or misheard speed/heading/altitude change on ATC request

3.2 Degraded Threat Management

Similar to the error management, current threat management relies on a two-pilot crew with the roles of the Pilot Flying and Pilot Monitoring. The management of threats is highly impacted by the overall workload of the crew resulting from the threats as well as by the ability of making reasonable decisions in order to maintain the safety margins. It is strongly dependent on the Shared Situational Awareness of the crew wich leads to a detection and assessment of threats in an early stage.

The following list was compiled at the CAT pilot workshop and contains situations from which potential threats can arise from in normal flight operations. Although this list has been carefully compiled, it may not be complete. Threats can arise from

- Adverse weather situations, quickly developing weather changes maybe in combination with airspace restrictions
- Traffic conflicts
- Unruly passengers
- Medical emergencies
- Undected loss of communication

3.3 Lack of Siuational Awareness

During Normal Crew Operation the two-pilot crew builds up a shared mental model and Shared Situational Awareness by exchanging observations and information. Both crew members monitor the flight and might detect a potential threat in an early stage. Each crew member contributes to the overall Situational Awareness. A negative impact on Situational Awareness is expected due to the missing crew member during the eMCO segment. On the other hand, according to workshop results, distractions in the cockpit might be reduced, if only one crew member is in the cockpit.

In case of a transition from eMCO to Normal Crew Operation and vice versa as well as a transition between the Pilot Flying (PF) and Pilot Resting (PR) it is essential to re-build a shared mental model of the situation based a

on a dedicated briefing. However, Situational Awareness of the PR might be negatively affected right after the transition resulting from the fact that he missed parts of the flight during the eMCO segment.

3.4 Fatigue and Boredom

One incentive to introduce eMCO is the expectation that flight crew fatigue might be reduced because both crew members will have the opportunity to rest. On the other hand the physiological and psychological effects of long single-pilot operations are not fully known. It is expected that such operation may impact the level of fatigue and boredome of the pilot, negatively affecting his or her performance. As part of this project Task 6 will assess how eMCO and the assumed associated resting cycle affects the alertness of the PF in terms of overall fatigure level and boredom, compared to today's operations in which two pilots are flying.

It is suspected that without any social interaction, boredom and drowsiness will increase [1, 2]. According to workshop results both crew members usually assess each other's fatigue level in current operation. The risk of the PF faling asleep during the eMCO segement without being noticed is assumed to increase if no additional measures are taken. Depending on the resting facilities it remains uncertain how good the quality of the rest will be.

3.5 Complacency / Adherence to Procedures

Complacency might increase if only one pilot is in the cockpit without the supervision of a colleague. This might affect the vigilance of the PF. With one pilot in the cockpit the adherence to the Standard Operating Procedures might be negatively impacted. This is supported by simulator studies performed by NASA [3].

This issue was also discussed during the CAT workshop. Participants mentioned the possibility that complacency might increase if the pilot is alone in the cockpit.

3.6 Sleep Inertia

The duration of sleep inertia is not definitely known, with some studies mentioning a duration of up to 30 min. During that time period the pilot's performance will be degraded in terms of his physical and mental abilities. Depending on the concept of operations sleep inertia will affect the PF's performance. To prevent this, the PR has to wait a certain amount of time after waking up before taking over the role of the PF. In case of an unplanned transition from eMCO to Normal Crew Operation, e.g. in case of an unplanned threat, the Pilot Resting may still be in a state of sleep inertia when the eMCO is aborted. In this case the PR's decreased performance has to be taken into account when assessing the impact on safety.

3.7 Degraded Decision-Making

Depending on the time-criticality resulting from an event, the PF has to begin with the decision-making process on his own. In addition to that, in case of an unplanned transition from sleep to active, the PR may still be in a state of sleep inertia for a certain time span after having entered the cockpit. As sleep inertia affects the coginitive capabilities this will most probably reduce his performance during the decision-making process. Decision-making schemes that are commonly used by airlines such as FORDEC guarantee sound decisions. Today the decision-making process in the cockpit is relying on two pilots that share their views and who might take opposite positions in order to reduce the effect of confirmation bias and target fixation.The impact on safety of just having one pilot involved in parts of the decision-making process has to be evaluated.

3.8 Workload Management

Even in normal operation during cruise flight situations with high workload might occur. It should be noted that workload does not only result from required actions in the cockpit but is impacted by operational constraints.

In the CAT workshop pilots stated that in case of a deviation from the flight plan the necessary coordination with the Airline Operating Center produces a significant amount of workload.

3.9 Company / Peer Pressure

The decision to abort the eMCO segment is left to the PF. A frequent abortion of eMCO will have a significant impact on the airline operations and related costs. In addition to that the abortion of eMCO might lead to a violation of flight time limitation regulations.

These constraints might put pressure on the PF during his decision-making process whether he should abort the segment or not. Peer pressure might also arise from the fact that the PF might be reluctant to wake up the PR due to a "minor" event.

3.10 Physiological Needs

Studies indicate that a person's mental performance decreases if he or she experiences pressure to go to the toilet. The PF has to trade off aborting the eMCO segment experiencing company or peer pressure against not going to the toilet until the end of the segment. This might create the additional hazard of a reduced performance of the PF.

3.11 Long-term Hazard – Missing Exchange between Pilots

During the pilot workshop the participants emphasized the importance of conversations between the two crew members during the cruise phase of a long-haul flight. The pilots described that a significant part of learning on the job takes part in this phase of the flight through the exchange of past experiences. This missing exchange might be considered as a relevant long-term hazard of the eMCO operations whose impact on safety is difficult to assess.

4. Relevant Scenarios Related to Hazards

4.1 General Events

4.1.1 Wrong or Missing Pilot Action

Basically any erroneous or omitted pilot action during the eMCO segment is a relevant scenario that is related to the lack of error management as it is usually performed in Normal Crew Operation. During cruise flight undetected erroneous inputs to the autoflight system could occur that might lead to vertical or lateral flight plan deviations.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Miscommunication with ATC	PF									
Input of wrong autopilot setpoint or activation of wrong autopilot mode	PF									

PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected

4.1.2 Breaks Due to Physiological Needs

Current concepts of operations foresee two solutions to cope with physiological needs:

1. Install a toilet as an integral part of the cockpit
2. Limit the maximum eMCO time so that the probability for physiological needs of the PF during that time span is relatively low. In case of urgent physiological needs the PF aborts the eMCO segment and wakes up the PR

In case of the second solution a situation might occur in which the PF experiences an urgent need to go to the toilet only a short time before the next planned transition with the PR. In that case the PF might decide to hold in urine or stool in order to prevent an abortion of the eMCO segment. This might lead to degradation of his or her performance during the remaining time of his eMCO segment.

Alternatively, the PF might decide to abort the eMCO segment leading to an unplanned transition.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Decide not to abort the eMCO segment							PF		PF	
Continue eMCo segment while holding in urine										PF
Decide to abort the eMCO segment and wake up PR							PF		PF	
Immeditately take over control from PF			PR			PR				

PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected

4.1.3 Planned Transition during eMCO

During a planned transition in the eMCO segment the challenge for the PF is to share his situational awareness with the PR entering the cockpit. According to the current eMCO concepts of operation a dedicated briefing shall be performed. However, it is a specific hazard resulting from the eMCO concept that the crew is not able to build up a shared mental model during the eMCO phase. The transition between the crew members combined with an event that requires a high degree of Situational Awareness is a relevant scenario.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Perform transition briefing			PR							
Take over control from PF		PR	PR				PR			

PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected

4.2 Events Leading to Route Adaptation

Generally, the necessity to adapt the route can significantly increase the workload during cruise flight. Depending on the situation and the future concept of operations the PF might decide to abort the eMCO segment or not.

4.2.1 Unruly Passenger Resulting in Diversion

An unruly passenger in the cabin is a relevant event that might reveal hazards that are specific to the eMCO operation. Depending on the severity of the situation the PF will have to contact the Airline Operating Center as well as ATC while re-planning the route and selecting a possible diversion airport. In case of an unruly passenger airline procedures might prevent the PF from opening the cockpit door. The crew rest may be outside the cockpit. In this case the PF is not able to abort the eMCO segment and is left alone in the cockpit further increasing his workload. In addition to that the PF either has to make all decisions on his own or, if available, has to use intercom to make the decision in collaboration with the PR.

Depeding on the applicable law the Captain who is either PF or PR has to make the final decision how to deal with the unruly passenger.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Decide to divert		PF	PF				PF			
Decide to abort eMCO segment and wake up PR							PF		PF	
Re-plan and optimize route							PF	PF		
Communicate with ATC and AOC								PF		
Communicate with cabin								PF		
Communicate with PR						PR		PF		

PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected

4.2.2 Medical emergency Resulting in Diversion

The occurrence of a medical emergeny in the passenger cabin triggers similar hazards as the unruly passanger scenario. Depending on the severity of the event the PF will have to contact the Airline Operating Center, the medical advisory hotline of the airline (if available) as well as ATC while re-planning the route and selecting a possible diversion airport. In contrast to the unruly passenger case the PR, if resting outside of the cockpit, is able to enter the cockpit and to support the PF. However, he might still be in a state of sleep inertia affecting his mental performance.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Assess medical emergency		PF						PF		
Communicate with cabin								PF		
Communicate with AOC/medical hotline								PF		
Decide to divert		PF	PF				PF			
Decide to abort eMCO segment and wake up PR							PF			PF
Re-plan and optimize route			PR			PR	PR	PF/PR		
Communicate with ATC and AOC/medical hotline						PR		PF/PR		
Communicate with cabin						PR		PF/PR		
Communicate with PR						PR		PF/PR		
PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected										

4.2.3 Deteriorating Weather at Destination or Alternate Airport

Deteriorating weather at the destination or alternate airport, possibly combined with a marginal overall weather situation, may significantly increase workload of the PF, as he has to re-plan and optimize the alternate routing while coordinating the changes with ATC and AOC. Decision making to select a new alternate airport will have to be performed by the PF without being supported by the PR. Depending on the situation the PF might call the PR and thus abort the eMCO segment.

During the workshop the participants also mentioned drone activities as a potential cause for airport closures. This might create an equivalent situation resulting in an airport closure for a certain time frame and requiring a decision from the crew whether to continue to the planned destination or not.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Assess the overall weather situation		PF	PF					PF		
Decide to divert							PF			
Decide to abort eMCO and wake up PR							PF		PF	
Re-plan and optimize route			PR			PR	PR	PF/PR		
Communicate with ATC and AOC						PR		PF/PR		
Communicate with cabin						PR		PF/PR		
Communicate with PR						PR		PF/PR		

PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected

4.2.4 Adverse Enroute Weather or Restricted Airspaces

Unexpected adverse weather or airspace closures on the planned route might trigger a necessary route adaptation resulting in an increased PF workload, as he has to re-plan and optimize the alternate routing while coordinating the changes with ATC and AOC. Decision making to design the new routing will have to be performed by the PF without being supported by the PR. Alternatively, depending on the situation or the concept of operations, the PF might call the PR and thus abort the eMCO segment.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Assess the overall weather or airspace situation		PF	PF					PF		
Decide to adapt routing							PF			
Decide to abort eMCO and wake up PR							PF		PF	
Re-plan and optimize route			PR			PR	PR	PF/PR		
Communicate with ATC and AOC						PR		PF/PR		
Communicate with cabin						PR		PF/PR		
Communicate with PR						PR		PF/PR		
PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected										

4.3 Pilot Incapacitation

Pilot incapacition during the eMCO segment is a significant hazard, as there is no pilot at the controls until the PR takes over the duties of the incapacitated PF. Moreover, the PR might still be in a state of sleep inertia which can delay the active involvement of the PR.

Pilot incapacitation can be differentiated between

- Subtle Pilot Incapacitation
- Full Pilot Incapacitation

Both types of incapacitation will be addressed in Task 5 of this project. Task 5 discusses solutions to detect both types, required automation functions until the PR is able to take over controls and different options to alert the PR. Task 4 will address the duration of sleep inertia and the impact on pilot performance.

The main hazard specific to the pilot incapacitation case is:

1. The monitoring sytem does not detect the pilot incapacitation and the alert for the PR is not triggered.

This hazard is dealt with in Taks 5. All other hazards triggered by the pilot incapacitation assuming that the PR is woken up and takes over control of the aircraft are listed in the following table.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Immediately take over control of the aircraft						PR				
Decide to divert		PR	PR			PR	PR			
Re-plan and optimize route		PR	PR			PR	PR	PR		
Communicate with ATC and AOC/medical hotline						PR		PR		
Communicate with cabin						PR		PR		
PF = Pilot Flying (before role change) affected, PR = Pilot Resting (before role change) affected										

5. Scenario Overview and Evalution

This section provides an overview of all scenarios described in Section 4. Each scenario is related to the hazards identified in Section 3. The table shall illustrate the capability of particular scenario contents to trigger certain hazards. All hazards that might occur during a scenario are marked with a cross in the corresponding cell.

Note that only hazards are marked that can be traced back to the introduction of eMCO. Hazards that are equally triggered for eMCO as well as NCO are not listed, e.g. degraded error management is not marked for the pilot incapacitation case, because this hazards results from the fact that one pilot is incapacitated and not from the special characteristics of the eMCO.

Scenario Elements	Error Management	Threat management	Lack of SA	Fatigue and boredom	Complacency / Procedures	Sleep Intertia	Degraded Decision-making	Workload	Company/Peer Pressure	Physiological Needs
Flight during eMCO segment w/o unusual events				X	X					
Wrong or missing pilot action	X									
Breaks due to physiological needs									X	X
Planned transition during eMCO		X	X							
Unruly passenger resulting in diversion		X	X			X	X	X[1]		
Medical emergency resulting in diversion		X	X			X	X	X		
Detiorating weather at destination or alternate airport		X	X				X	X		
Adverse weather or restricted airspaces						X	X	X		
Pilot incapacitation			X			X	X[2]			

Based on the scenario overview a pre-selection of the most relevant simulator scenarios for nomimal opoeration that will be performed as part of this project is performed.

Three different simulator studies will carried out (see *D2.2 Detailed Research and Test Acticity Plan* [4]):

[1] In the unruly passenger case the workload might be significantly higher as for the medical emergency case if the PR is not able to return to the cockpit.

[2] Degraded decision-making due to lack of SA

- Simulator study on nominal operations
- Simulator study on failure condition management
- Combined simulator study on sleep inertia, fatigue and boredom

Note that this deliverable focusses exclusively on nominal operations.

5.1 Hazards vs. Simulator Scenarios

Wrong or missing pilot action

Although the risks resulting from wrong or missing pilot action due to the lack of crosschecks during the eMCO segment might be very relevant, it is usually not feasible to design a simulator scenario that is capable of triggering these errors reliably. However, it might arise during every scenario that will be conducted for the three dedicated studies. A wrong or missing pilot action that will be detected during the studies will be carefully evaluated in terms of their root cause, such as sleep inertia, missing crosschecks or workload mainly based on the video recordings.

Threat mangement

Each scenario that will be performed during the three studies shall include certain external threats, such as adverse weather or a medical emergency. The impact of eMCO on the crew's threat management will be assessed based on video recordings.

Lack of situation awareness

The potential adverse impact on situation awareness during the eMCO segement but also after transition from eMCO to Normal Crew Operation shall be in the focus of the nominal as well as of the failure condition management studies. The selected scenario shall result in a complex situation requiring a high degree of situational awareness.

Fatigue and boredom

Fatigue and boredom are analysed on a dedicated taks of this project (Task 6). As decribed above a dedicated simulator study combined with the sleep inertia study will be performed as part of Task 2. Further details on the experimental design for this study can be found in [4].

Complacency / Adherence to procedures

Potential complacency and reduced adherence to procedures might arise in long eMCO segments without significant events. Although it is very hard to trigger in simulator trials, it might be observed during the fatigue and boredom studies.

Sleep inertia

The impact of sleep inertia will be analysed in a dedicated experiment combined with fatigue and boredom. Hence, for nominal operations studies, the focus is not put on sleep inertia. To separate the impact of sleep inertia from other hazards, the task of the nominal operation studies is to prevent the PR from being in a state of sleep inertia when taking over his duties again.

Degraded Decision-making

The focus of the nominial operation study shall be put on assessment of the decision-making process as the risk of a degraded decision-making process is strongly related to the potential lack of situation awareness and threat management. This requires a scenario leaving the crew on a complex, diffuse situation requiring a complex decision and a high degree of communication.

During eMCO operation the PF's decision whether the eMCO segement shoud be aborted or not is expected to be significant safety factor. A scenario with a slowly deteriotating situation resulting in a unclear decision w.r.t to the abortion of the eMCO segment shall be included in the studies.

Workload

It is expected that a extensive workload might be a significant hazard during certain nominal scenarios. The selected scenario shall result in an increased workload situation.

Company and peer pressure

It is not possible to trigger company and peer pressure in a simulator scenario.

Physiological needs

The impact of physiological needs as a potential hazard will be analysed in a dedicated workpackage (Task 7).

5.2 Pre-selection of Suitable Nominal Operation Scenarios

The most suitable scnearios in terms of workload, situation awareness as well as decision-making are the following

- Unruly passenger resulting in a diversion
- Medical emergency resulting a a diversion
- Deteriorating weather at destination or alternate airport

The "unruly passenger" and the "medical emergency" scenarios are very similar scenarios triggering similar hazards. The "unruly passenger" scenario has the additional complication that the pilot resting may not be able to return to the cockpit further increasing the workload of the PF.

The "detiorating weather" and "adverse enrouter weather" scenarios have a reduced workload level in comparison to the preceding scenarios. However, it can be combined with the other two scenarios to further assess the impact of eMCO on situation awareness and decision-making.

The pilot incapacitiation scenario is not suitable for simulator experiments.

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References

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Annex A CAT Pilot Workshop Results

A.1 Personal Experience

Workshop-Question:
Describe, from your own personal experience, a situation during cruise flight where a second person in the cockpit was absolutely necessary for the safety of the flight.

A.1.1 Anecdotal Examples described by the participants

- *"Night flight, tired, couldn't stay awake and need to take a short nap, couldn't t do this without a second pilot."*
- *"Night flight, cabin door (from the cabin to the flight deck) can be jammed due to cabin pressure , second pilot needed to help open the door."*
- *"I was a FO to a long haul flight to Kuala Lumpur. Suddenly the airport closed due thunderstorms. We needed to coordinate with ATC, see what airports wereare available, evaluate risks and benefits, and do changes to the FMS. Three of us evaluated the situation, gathered information and discussed solutions. Hard to imagine doing that on one's own, only interacting with (current) automation."*
- *"We had four cases of medical emergency on the same flight, two developed at the same time. Row 4a and 4L showed similar health problems, but not the same. Confusion of the cases was easy due to them being on the same row. It wasn't clear in the beginning that these were two cases. Communication with the cabin crew kept us busy. Deteriorating, getting better, deteriorating, getting better (between 4A and 4L). Problem solving and decision making on alternate airport (situation could have been worse if not over Europe). Coordinating with cabin crew, ATC, medical hotline. 1st one under constant oxygen, 2 and 3 developed, diversion to Deli? Can we take off there again? How many oxygen bottles do we have left? It was an operational scenario that is not covered in the books."*
- *"[Airline] once had a four engine flameout. When the captain returned to the flight deck to the two FOs he decided to remain on the jump seat, which yields a pretty good overview of the whole cockpit situation. From there, he restarted the engines."*
- *"My captain had a subtle incapacitation below 500 ft AGL, he didn't react to my callouts "below glide slope" and showed no other reaction until after touchdown. So I took over controls at 500 ft AGL and performed the landing."*
-

A.1.2 General Issues mentioned by the participants

- Weather avoidance decision might require two pilots
  - How to get around the weather system is hard to decide even with more pilots and knowledge on board. Divert to the right, or to the left?
- The remaining pilot is more prone to target fixation if there is no counter voice.

A.2 Addition/Enhancements to List of Scenarios (Only Nominal Operation)

Workshop-Question:
Based on the presented list of scenarios please add relevant scenarios or events.

First, the list of scenarios that was generated in Task 1 was presented to the workshop participants (see…):

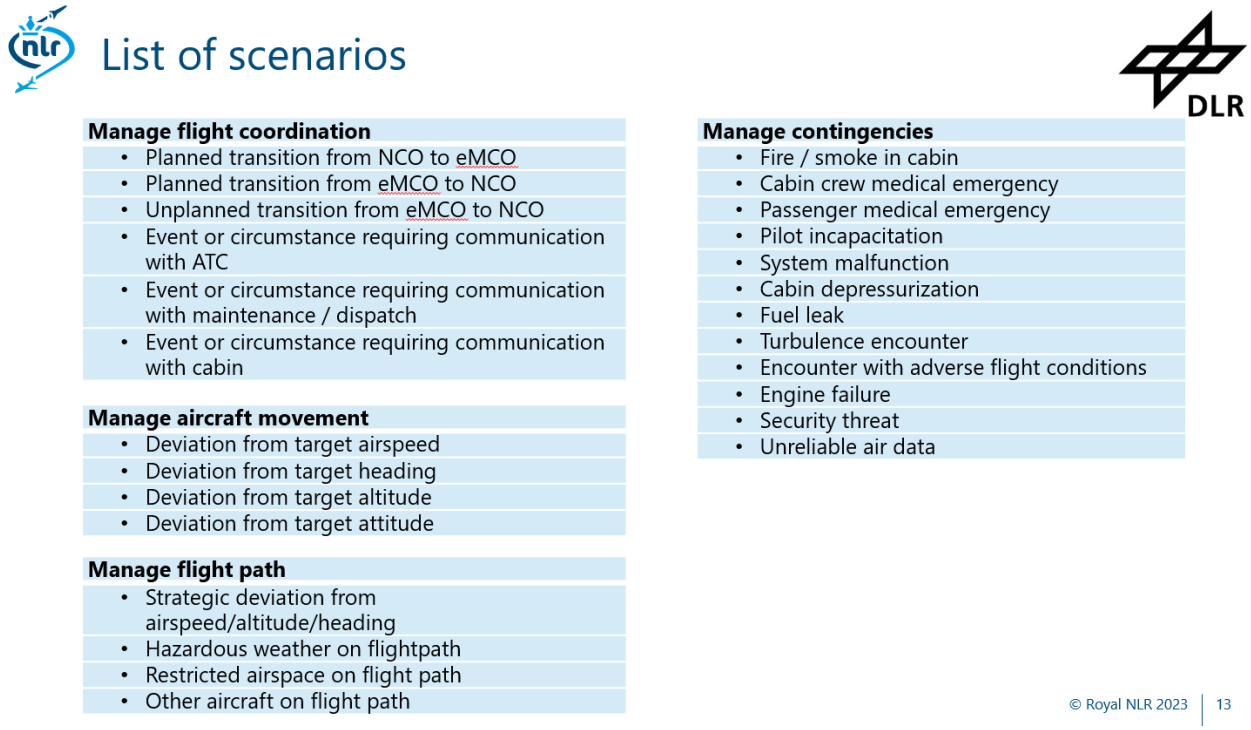

Figure 1: Screenshot of workshop slide listing all scenarios identified before the workshop

The participants mentioned specific nominal scenarios or scenario elements listed in the following bullet points:

- Deteriorating weather at destination or alternate airport.
- Head wind stronger than expected which calls for route adaptions due to increase in fuel consumption (contingency diversion)
- Turbulence can be an aircraft movement, flight path issue, but can also be a source for medical problems
- Situational awareness, decision making, problem solving. how is that affected, e.g. in case of a quick drift down. The whole non-technical side. How is it envisioned to transfer the mental model to the other pilot when he/she returns to the flight deck?
- Situational awareness evaluation: How do we transfer the mental picture from one to the other?
- Extremely developing/dynamical weather situation with high traffic, airports are closing suddenly.
- Drone sighting (airport closes for 30 minutes)
- Example: Very dynamic situations, is the Plan B still valid or not, diversion, Alternate is closed because of too many aircraft or of drone activity
- Targeted Operational environment (Europe? Asia? Africa?) --> Airspaces without CPDLC, Radar, deficient airspaces as defined by ICAO). At the moment all airspaces are considered. Airspaces willl affect risk level.

A.3 Scenarios with the Highest Risk (Only Nominal Operation)

Workshop-Question:
Which three scenarios have the highest risk? (only nominal)

- **Pilot incapacitation:** high probability of the event, hard to monitor, makes perhaps erroneous actions
- Current diagnostic not perfect, but might be an outcome of this study that it needs to be!
- **Route Adaptation**
  - Politically closed airspaces combined with weather systems, closed up to certain level, unaware of closed airspace
  - Airspaces are (politically) closing up, very nicely hidden in the NOTAMS
  - High workload: Constant updates on connection flight, Eurocontrol vs. Operator
- **Unruly passenger** most often develops in cruise flight, might even hinder the second pilot to return to the flight deck. To what extend is one allowed to ignore the cabin? The captain is the final authority, only he can officially order to restrain the unruly passenger. In case of two FOs and the Captain sleeping he has to be woken. Might be that he cannot get into the cockpit, unless measures are taken to prevent the unruly from entering the cockpit. Cannot be transferred
- **How often do you experience missing cross-checks?**
  - Multiple times a day pilot errors are prevented due to missing crosschecks
  - Examples: lost communication, only partly activated Direct To, forgotten to change speed on ATC request, FMA checking
- **Flight plan optimization** (connecting flights, fuel) keep quite busy
- Loss of communication with ATC (often you do not realize the loss), rate of failure on the ATC side is impacting the risks. Should ATC know that we are in an eMCO segment ?
- **Cyber threats**
  - www.Gpsjam.org
  - Subtle attack might be much harder to detect in case of one pilot, GPS, CPDLC
  - Is already a problem of today, but plausibility check even harder for only one pilot
  - Very hard to detect with existing systems
  - A350: in case of re-routing Airbus proposes to upload a new flight plan to the aircraft
  - GPS jammed time (which ran much faster) was used in fuel system to integrate fuel flow, so the fuel amount emptied unreasonably quick.

A.4 Factors Influencing Pilot's Performance

Workshop-Question:
What are factors that influence pilot performance (stress, fatigue, training ,experience, high and low workload)?

- **Boredom and Vigilance**
  - Being two in the cockpit does not only have positive effects on vigilance, distraction might be higher with two pilots
  - If one pilot leaves the cockpit and you are alone, you put a little bit more effort/increase your alertness because there is no one to catch your errors. Ok to keep that for a short amount of time (toilet break), but tough to keep it for 2.5h.
  - Flying alone is more demanding than together, but together it can also be more distracting.

- **Experience**
  - **Sharing experience**/transfer of knowledge from previous flights. Not much time left for this, because below **FL100** there is the **sterile cockpit**.
  - Distinction between total experience and on type experience has to be made, because you cannot learn from more experienced crew members like today.
- ***Question Workshop Host*: How much learning takes places on the job?**
  - Maybe more than a fifth
  - You learn most from your colleagues not from the few weeks of line training
  - You learn how to organize yourself.
  - Takes about a year approx. Until you're fully confident up to 500-800 hours. Most of the techniques are taught during cruise
  - Social interaction is a huge factors, you learn most from the colleagues
  - Internal LH study (25 years old): Contributing factors on incident and accidents: Worst effect was lack of crew interaction
- ***Question Workshop Host*: Is extremely low workload a worry**?
  - At night, over the Atlantic, no small talk, no cabin crew interaction. Chit chat has the effect of fighting boredom; early sign if other colleague is getting fatigued/prone to falling asleep
- ***Question Workshop Host*: How is the workload fluctuating? Are there patterns?**
  - High density areas (due to traffic) and you don't get the flight level that you want --> detrimental effect on fuel situation
  - Being late increases workload, because you are trying to optimize
  - Weather (both turbulence and thunderstorms / icing)
  - In general: if something goes different than planned
  - Medical emergency: went on for two hours
- ***Question Workshop Host*: How often do you discuss what-if scenarios?**
  - *"Not very common"* but at the same time *"perhaps once or twice per hour"*. You draw circles of what airports are in range.
  - *"You're always working on your situational awareness, boundary between chit chats and official talks are narrow."* Not necessarily happening in a separate way
- **Complacency**
  - What if you bring your iPad and watch a movie or play a game and don't monitor the systems anymore?, adherence to procedures lower
- **Distraction**
  - If cabin crew enters the cockpit, where do you look at / invest your visual capacities? At the cabin crew, or do you keep your face/attention to the cockpit? In the two pilot case one is focusing on entering crew and one on the cockpit.

A.5 Specific Topics Discussed with Participants

Workshop-Question:
Discuss specific topics with the participants listed on the presented slide

Specific topics:

- Adherence to sleep inertia protocol: pilot is not supposed to interact when suffering from sleep inertia.
- Donning of oxygen mask (pilot flying and pilot resting).
- Abortion of the eMCO segment. Decision that (in some cases) must be made by the pilot flying (alone). What are factors influencing this decision? Company pressure, reluctance to wake up colleague for a minor issue?
- Confirmation bias? First diagnosis is performed by single pilot. Does this affect the diagnosis of the pilot coming back to the cockpit? How? Do you have examples of such cases?

Figure 2: Screenshot of workshop slide presenting additional specific topics

A.1.3 Adherence to sleep inertia protocol/procedures

- ***Question Participant*: How do I recognize that I'm suffering from sleep inertia?**
- ***Question Workshop Host*: How realistic is it to enter the cockpit and do nothing for a fixed amount of time?**
  - *"If you're in the cockpit, you assume your role"*
- ***Question: Do you realize the effects of sleep inertia?***
  - Yes, slower reaction times
  - Your reception is worse
  - Takes a while, get your briefing in bits and pieces
  - Example: fire alarm in the middle of the night. You see different stages of readiness/alertness. Some of it will depend on how alert they are.
  - What if you couldn't sleep at all? Do you have to keep to sleep inertia rules? Aren't you allowed to do anything at all?
  - Quality of sleep: Different periods of the flight have different quality of rest. Usually we send the second officer first, because you cannot sleep well directly after takeoff, or a high workload phase, respectively

A.1.4 Abortion of the eMCO segment

- Peer pressure / company pressure might be a big issue, e.g. you have to fill out a form. What if you abort often? Do you lose your eMCO certificate (as company, cf. ETOPS)?
- Just like ETOPS might induce pressure: if you have too many abortions, you may lose your FTL credits
- You might not see that your workload is continuously increasing until there is no capacity left to call for assistance/introduce the situation to assistance.

- *"I was a young first officer on company starting with ETOPS, flew back with throttle in the idle position. If I would have turned off the engine then we would have lost the EOPS certificate."*
- Alternates decision might not change often during long haul flights
- Reasons for abortion: unruly passengers
- Weather avoidance? Maybe very rarely, e.g. in case of large squall lines
- If there is technology that can support you, you could perhaps let the PR sleep
- Availability of the internet/data connection has an impact on eMCO segment
- *"We use flightradar24 over internet when over Africa for seeing where most of the traffic is going around a weather system."*

A.1.5 Confirmation bias

- **Idea for simulator experiments:** Needs further research; ex. In a 3 pilot crew with 2 on the flight deck and the third called from the bunk, the third one is presented with all the facts and then asked for his/her opinion, without preoccupying his/her mind with a possible solution, to get an uninfluenced opinion
- Research setup to see if some creativity is taken out in single pilot situations
- **Resources for briefing:** Currently, we have the time for that, because there are two pilots and one of them can brief the third. If the single pilot has to do this while managing the aircraft, this briefing cannot be thoroughly performed
- Initial actions just performed by one pilot might lead to a wrong conclusion

A.1.6 **Problem solving & decision making**

- "Pilots don't do a lot of diagnosis anymore, systems do this today, we just read the info from ECAM/EICAS."
- Simple engine failure is easy, but complex failures, spurious warnings, e.g. inverse fuel reading, are more demanding
- FORDEC would have to be strictly applied
- Sat-phone is not possible when you are alone in the cockpit, e.g. medical support line, trouble-shooting hotline
- ***Question Workshop Host: Can FORDEC be transferred to one person?***
  - **In theory yes, but the confirmation bias might not be overcome. Other reasons and other options might be overlooked.**
  - Example: engine stall and subsequent damage over high terrain, drift down to Milano
- ***Question Workshop Host:*** **How will it affect your decision if you don't have the history of the failure?**
  - If there is no time-criticality there is a chance that can be overcome by a **thorough briefing**. But not if you don't have time. Quality of the decision might be worse, bc. Input is worse.
  - What-If planning in developing situations (e.g. developing medical, currently we can have a call with med services already and plan for contingencies, but not if you are alone)
  - Reluctance to wake up colleague, because briefing him would bind resources that you don't have at that time anymore (see example with continuously increasing workload above).
  - New strategies will have to be developed to overcome **confirmation bias**. Let him find out what threats and problems out and compare it with what you have found out, talk about it…. But that's not realistic.

A.6 Additional Collected Untouched Topics

Workshop-Question:
Which additional topics w.r.t to eMCO do you see that we touched during this workshops?

- **Training**
  - How do you do something with two pilots, how with only one?
  - Do we have the skill and competencies to fly the aircraft alone?
  - MPL vs. ATPL → ***Question Participant: Can a MPL pilot be the only pilot on the flight deck for an eMCO segment?***
  - During takeoff and landing you want a team player, and during eMCO you're looking for a military pilot, different selection criteria for different segment of the flight
  - ***Question Participant:*** How is the initial training affected ?
- **Procedures**
  - Current procedures are call & response. This would have to be redesigned.
  - Example:Switching on the XPDR: changed who does it (not when) leads to failures (not switched on at all).
- **Medical issues**
  - ***Question Participant:*** Do we need to have a class 1a medical, so above the current class 1 medical?
- Showing equivalent level of safety will not be an easy task
- Swap between roles, how does that work? Change of situation quite often, several times
- **If solution is to increase automation:** every system creates confusion or takes out of the loop. That might create new risks we don't know yet and don't know how to cover this in a research project.
- How do we deal with a situation when there is no good solution? Especially where you stick to the procedure AND there is no solution (e.g. QF32) AND you're initially alone!?
- Subtle incapacitation detection will be a big challenge.

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