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D-9 FINAL REPORT ON RISK ASSESSMENT FOR EMCOS AND SIPOS

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

An Agency of the European Union

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SUMMARY

This final report of the Extended Minimum Crew Operations-Single Pilot Operations (eMCO-SiPO) research project considers a risk assessment and impact analysis of eMCO. A risk assessment of SiPO is described in a separate project deliverable: D-8.

Problem area

Aircraft manufacturers have expressed an interest in eMCO, proposing that the high levels of automation that are already available in the cockpit allow extended periods of the cruise flight to be executed with a single pilot in the cockpit while the second pilot is sleeping. According to aircraft manufacturers, advanced aircraft systems can be combined with new procedures and training as a basis towards more autonomous operations such as eMCO and potentially leading to SiPO. The main question (from the perspective of eMCO) for the current study is whether eMCO can be introduced with an equivalent level of safety as normal crew operations - the current situation where two pilots fly the aircraft together (taking into account the exception of an incidental controlled rest). This document is the final report of that aspect of the study and describes the findings of the different research topics that were considered.

Description of work

The project established a safety framework to consider the different potential risks associated with eMCO. The framework consists of the results of the studies on these different subtopics considered within this project:

- An overall risk assessment
- A description of feasibility, effectiveness and consequences (for example for regulation) of solutions and mitigations which were offered by the industry, or were identified by the researchers during the the project. Feasibility and effectiveness were described in terms of safety impact, changes to existing procedures, training methods and associated constraints (such a costs).
- Operational benefits and other impact elements

The current deliverable brings together all of the findings from the safety framework subtopics to describe the forecasted effect on safety, based upon the knowledge of eMCO and the expected technological and procedural adjustments that may be introduced to enable eMCO.

This study also provides a first impact analysis of eMCO, considering economic, safety, social and environmental impacts.

Application

The factual findings of this study are relevant for EASA as input for their Rulemaking Task RMT.0739 (introduction of extended minimum-crew operations- eMCO), and any associated regulatory efforts within the agency. They can also be used in the discussion that is taking place in society regarding the impact of eMCO. The scientific findings from the current study can serve as stated facts in that discussion, such that less speculation will be needed in order to identify the impact of eMCO, facilitating a balanced discussion of the technological advancements and operational efficiency with uncompromised operational safety standards on the other hand.

CONTENTS

ABBREVIATIONS

ACRONYM	DESCRIPTION
A/C	Aircraft
AC	Advisory Circular
ACAS	Airborne Collision Avoidance System
ATC	Air Traffic Control
CAA	[UK] Civil Aviation Authority
CAT	Commercial Air Transport
CBA	Cost Benefit Analysis
CBTA	Competency-Based Training and Assessment
CONOPS	Concept of Operations
CPDLC	Controller Pilot Data Link Communication
CRM	Crew Resource Management
DBL	Deep Blue
DLR	German Aerospace Centre
EASA	European Union Aviation Safety Agency
EBT	Evidence Based Training
EFB	Electronic Flight Bag
eMCO	Extended Minimum Crew Operation
FAA	Federal Aviation Administration
FMS	Flight Management System
FORDEC	Facts, Options, Risks & Benefits, Decision, Execution, and Check
FSTD	Flight Simulation Training Device
GPS	Global Positioning System
HF	Human Factors
HMI	Human Machine Interface
ICAO	International Civil Aviation Organisation [UN]
MCO	Minimum Crew Operations
MPL	Multi-Crew Pilot Licence
NCO	Normal Crew Operations
NLR	Royal Netherlands Aerospace Centre (Dutch: Koninklijk Nederlands Lucht- en Ruimtevaartcentrum)
OEM	Original Equipment Manufacturer
PERCLOS	Percentage Of Eyelid Closure
RA	Resolution Advisory
RMT	Rule Making Task
SiPO	Single Pilot Operation
VTE	Venous Thromboembolism

1. Context

1.1 Background

Due to the ongoing developments in technology, automation and autonomous aircraft, there is an interest and desire to explore whether it is feasible to operate large commercial air transport (CAT) aeroplanes with reduced flight crews. The technological developments have improved the resilience of the aircraft systems, existing aircraft already have high levels of automation and manufacturers are developing further systems to assist the pilot and support reduced crew operations. In this project, the feasibility of Extended Minimum-Crew Operations (eMCO) is considered from both the safety as well as efficiency perspectives, with the goal of maintaining safety standards equivalent to current two-pilot operations.

Current EASA regulations mandate the presence of two pilots for CAT operations involving aircraft with more than nine passenger seats, or all turbojet aeroplanes. Single-pilot operations are only permitted for specific turboprop aircraft under certain conditions. To accommodate eMCO EASA has initiated this EU Horizon research and Rulemaking Task RMT.0739 to develop a regulatory framework that ensures safety levels are maintained or enhanced with reduced crew operations.

EASA was approached by aircraft manufacturers regarding the regulatory and safety aspects of such new concept of operations (CONOPS). Two specific CONOPS were identified, namely Extended Minimum-Crew Operations (eMCOs) and Single-Pilot Operations (SiPOs).

The aspects related to SiPO are described in more detail in report D-8 of the current project.

Extended Minimum-Crew Operations (eMCOs) is an operational concept where one pilot can be at the controls during the cruise flight phase of commercial flights. The intent is to ensure an equivalent overall level of safety to current two-pilot operations, through various 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, with the aim of reducing the number of pilots required on long-haul flights.

The main challenges when moving from conventional multi-crew operations to eMCO, and also to SiPO, includes ensuring adequate detection of pilot incapacitation, as well as sufficient risk mitigation in case of incapacitation, including mental health issues (EASA, 2023). The impact of eMCO on the workload and fatigue for the pilot flying (PF) is another consideration that was taken into account in the study.

1.2 Scope of the document

This document provides an overview of the foreseen impact on safety that flying according to the eMCO concept may have. It also provides the final conclusions of the current study on the extent to which equivalent levels of safety can be accomplished when flying according to eMCO CONOPS. Note that not all technological as well as procedural approaches towards enabling eMCO, as foreseen by the industry, were available to the researchers when executing the current study.

The document also provides a first analysis of the impact that flying according to the eMCO concept may have.

1.3 Methods

This report is based upon previous work that was executed within the current study, and published into the different deliverables. Relevant information for these deliverables was gathered through literature reviews, interviews with industry, a large scale survey, and two high fidelity simulator experiments.

The project started off by creating a risk assessment framework (D-1.2) describing how current operations are executed by normal crew operations with a crew of two pilots being present in the cockpit throughout a whole flight. In the current deliverable, this framework is compared against the eMCO situation where, during eMCO segments one pilot is resting and the other is controlling the aircraft alone. It is recommend to read that risk assessment framework in order to better understand the current report.

A separate simulator study (D-6.2) about sleep inertia (D-4), fatigue and boredom (D-6) that was executed in an A320 simulator, and a simulator study (D-2.6) which focused upon normal and abnormal operations during eMCO segments that was executed in an A350 simulator, were used as input to the risk assessment framework. Further the theoretical studies about these topics, as well as about pilot monitoring (D-5), incapacitation (D-5) and physiological needs (D-7), were used to fine-tune the risk assessment framework.

A complete overview of all published deliverables of the report is included at the bottom of the reference list. The reports themselves may be downloaded from: https://www.easa.europa.eu/en/research-projects/emco-sipo-extended-minimum-crew-operations-single-pilot-operations-safety-risk#group-downloads.

1.4 Readers guide

In Chapter 2, the potential risks associated with eMCO, emerging from the risk assessment framework, are described.

In Chapter 3, the potential impact of eMCO on economic, social, safety and environment is shown.

Finally, in Chapter 4 the most important conclusions from the different subtasks as well as the answer to the main question whether eMCO has an equivalent level of safety as normal crew operations, is provided.

In order to avoid confusion between the eMCO and SiPO concepts, the project's findings regarding SiPO are described in a separate deliverable (D-8).

2. Application of the risk assessment framework

In this section, the baseline risk assessment framework that is described in eMCO SIPO deliverable D-1.2 is used. The baseline risk assessment framework is scenario based with four main categories of scenarios, corresponding with high level flight crew tasks:

- Manage flight coordination
- Manage aircraft movement
- Manage flight path
- Manage contingencies

The eMCO SIPO research tasks on failure condition management, sleep inertia, pilot incapacitation management, pilot fatigue, boredom and physiological needs are described in the context of each of the scenarios, highlighting the consequences for flight safety.

2.1 Effects of eMCO on the risk assessment scenarios

<u>Scenario 'Planned transition from Normal Crew Operations (NCO) to eMCO'</u>
A planned transition from normal cruise operations to eMCO can only take place if the prerequisites for eMCO are met. According to information received from Original Equipment Manufacturers (OEMs) this means that the automatic flight control system is engaged, there are no failures that would require abort of the eMCO segment and there are no environmental (e.g. weather) or other external (e.g. airspace, ATM) circumstances foreseen that would require abort of the eMCO segment. The transition from normal crew operations to eMCO is achieved by a dedicated briefing that includes a review of the aircraft status, a review of the projected flight during eMCO, a review of abnormal procedures during eMCO and a review of the expected aircraft and flight status at the end of the eMCO segment.

The transition briefing is an additional task compared to normal crew operations and adds to the workload. An incomplete or incorrect briefing may result in incorrect situational awareness of the pilot flying. The likelihood and consequences of an incorrect transition briefing depend on the design of the aircraft system that supports the transition briefing. Because OEMs have not provided details of these systems, the effectiveness of these systems in supporting the flight crew cannot be estimated.

In normal crew operations, transition briefings take place before a period of controlled rest of a pilot and when in-flight crew changes take place during flights operated by augmented crew. EASA Rules for Air Operations do not include implementing rules, acceptable means of compliance or guidance material on transition briefings for flights operating with augmented crew. In the case of controlled rest, EASA guidance material states that an adequate briefing should be given, without specifying the content of the briefing. [EASA Rules for Air Operations, Annex IV (Part-CAT), Subpart B: Operating Procedures, GM1 CAT.OP.MPA.210 Crew members at stations, Mitigating Measures — Controlled Rest (e) *When applying controlled rest procedures, the commander should ensure that:*
(1) the other flight crew member(s) is (are) adequately briefed to carry out the duties of the resting flight crew member].

The results from the simulator experiments on failure condition management (see project deliverable D-4) suggested that the transition briefing at the beginning of the eMCO segment should include a detailed discussion on potential alternate airports and related weather during the eMCO segment.

Scenario ‘Planned transition from eMCO to NCO’

A planned transition from eMCO to normal crew operations requires a transition briefing to allow resynchronisation of the pilot resuming flight related activities with the mission and flight status. It is assumed that the transition briefing can only take place if the sleep inertia of the pilot resuming flight activities has ended. While recovering from sleep inertia and before the transition briefing takes place, the pilot resuming may already start self-synchronisation by reviewing aircraft status pages, updated weather information, navigation logs etc, without disturbing the pilot flying. The transition briefing includes a review of the aircraft and flight status and a report of activities and actions that occurred during the eMCO segment. After the briefing the pilots make agreements on task sharing during the next segment (which may also be an eMCO segment).

The transition briefing is an additional task compared to normal crew operations and adds to the workload. An incomplete or incorrect briefing may result in incorrect situational awareness of the pilot resting and confusion about distribution of tasks. The likelihood and consequences of an incorrect transition briefing depend on the briefing procedures and the design of the aircraft systems that may support the transition briefing. Because OEMs have not provided details of these systems, the effectiveness of these systems in supporting the flight crew cannot be estimated.

In normal crew operations, transition briefings take place after a period of controlled rest of a pilot and when in-flight crew changes take place during flights operating with augmented crew. EASA Rules for Air Operations do not include implementing rules, acceptable means of compliance or guidance material on transition briefings for flights operating with augmented crew. In the case of controlled rest, EASA guidance material states[1] that an appropriate briefing should be given, without specifying the content of the briefing. The duration of controlled rest periods (maximum 45 minutes) is shorter than the foreseen duration of the eMCO segment (120-150 minutes). Therefore, a briefing after an eMCO segment is expected to be more extensive than a briefing after a controlled rest period.

The simulator experiment that included a planned transition from eMCO to normal crew operations (see project deliverable D-4.2 and D-6.2) did not identify or highlight any specific issues or concerns related to a planned transition from eMCO to normal crew operations. Please not that this experiment included a low number of participants for which the results should be interpreted with caution.

Scenario ‘Unplanned transition from eMCO to NCO’

In case the essential conditions for eMCO are violated, an unplanned transition from eMCO to normal crew operations is required. The steps to be performed are similar to the steps of a planned transition from eMCO to normal crew operations, but depending on the level of urgency of the situation, some steps may be cut short or surpassed.

In normal crew operations, a period of controlled rest or rest of augmented crew members may be ended prematurely. Airlines may have company procedures with conditions that require premature ending of such rest periods and details on how crew briefings must be done. There are no specific implementing rules, acceptable means of compliance or guidance material on transition briefings for rest periods that end prematurely. The decision is therefore based on pilot operational judgement. In normal crew operations

[1] EASA Rules for Air Operations, Annex IV (Part-CAT), Subpart B: Operating Procedures, GM1 CAT.OP.MPA.210 Crew members at stations, Mitigating Measures — Controlled Rest (f) 3 After this 45-minute period, there should be a recovery period of 20 minutes to overcome sleep inertia during which control of the aircraft should not be entrusted to the flight crew member. At the end of this recovery period, an appropriate briefing should be given

there is the possibility of cross check on a decision made to prematurely end a rest period of augmented crew, however, the decision to prematurely end a period of controlled rest has to be made by a single pilot. From a perspective of risk, the scenario 'unplanned transition from eMCO to normal crew operations therefore is similar to a normal crew operations scenario where one crew member is taking a controlled rest and a situation develops in which the pilot flying needs support and decides to wake up the resting pilot.

In this scenario the pilot flying needs to brief the pilot resting while the conditions are abnormal. This may result in high workload. The likelihood and consequences of an incorrect transition briefing depend on the design of the aircraft systems that support the transition briefing in abnormal conditions. Because OEMs have not provided details of these systems, the effectiveness of these systems in supporting the flight crew cannot be estimated.

Results from the simulator experiment on sleep inertia, fatigue and boredom (see project deliverables D-4.2 and D-6.2) showed that after the abort of an eMCO segment, crews reported difficulties in coming together as a crew again, partially due to the pilot resting just waking up, but also due to the pilot resting being out of the loop for an extended period of time. During the experiments specific procedures for a transition briefing were not provided to the flight crew. The results could therefore demonstrate the need for specific transition briefing procedures to support recovery of the crew as a team.

Results from the from the simulator experiment on sleep inertia, fatigue and boredom (see project deliverables D-4.2 and D-6.2) did not show effects of sleep inertia on the performance of the flight crew in the event of an aborted eMCO, but results from previous literature (see project deliverable D-4) suggest a duration of sleep inertia of up to 35 minutes to be taken into consideration.

The results from the simulator experiments on failure condition management (see project deliverable D-4) showed that most participants had difficulty adhering to the eMCO procedure on the sleep inertia recovery period. Several pilots pointed out that a procedure with a fixed recovery time is somewhat artificial and not feasible in real world operations. Especially in case the pilot resting is the pilot in command, it was considered unrealistic not to be actively involved for a fixed period.

<u>Scenario 'Event or circumstance requiring communication with ATC'</u>
In the eMCO CONOPS, the pilot flying is performing the three basic piloting tasks (aviate, navigate, communicate) while these tasks are shared between the pilot flying and pilot monitoring in the normal two pilot CONOPS. The following potential issues are relevant:

- Workload
- Likelihood that critical information from ATC is not received or understood by the pilot flying
- Likelihood that critical information is not provided to ATC by the pilot flying
- 'Party-line'.

Compared with a two pilot CONOPS, an event or circumstance requiring communication with ATC during eMCO results in higher workload for the pilot flying. The eMCO CONOPS envisions that the pilot flying will abort the eMCO segment if the workload is considered too high for a single pilot. This eMCO scenario is similar to a normal crew operations scenario where one of the pilots takes a controlled rest, with the exception that the rest period in the eMCO CONOPS is envisioned to be longer than during a controlled rest.

During the simulator experiment on sleep inertia, fatigue and boredom (deliverable D-4.2/6.2), workload of the pilot flying during the eMCO segment was rated at or below a comfortable, busy pace.

While resting, the pilot resting is not able to use ‘party line’ information to maintain situational awareness with respect to other aircraft and the environment. However, the effect of party line information on the ability to maintain situational awareness during cruise flight is limited (Hansman et al, 1995) and the background noise provided by ATC chatter possible impairs flight task mental activities (Hodgetss et al, 2005). The information available by party line communications can be presented in a more reliable, available and intuitive manner (Hansman et al, 1995). A means to review an overview of relevant ATC messages, and updates on the location of other aircraft and environmental conditions that have occurred during the rest period, could support the pilot resting in building a proper situational awareness when resuming activities following a rest period.

Requiring the use of Controller Pilot Data Link Communication (CPDLC) may be a prerequisite for eMCO operations because this could reduce the likelihood of miscommunication and will provide support to the pilot resting in regaining situational awareness after returning to the cockpit.

Scenario ‘Event or circumstance requiring communication with maintenance / dispatch’

Flight dispatchers or flight operations officers collaborate with the flight crew from the airline’s operations centre. During the flight the operations centre monitors the progress of the aircraft and provides updates to the flight crew if necessary. Pilots can communicate with the operations centre and with the airline’s maintenance crew to obtain operational or technical information and advice.

Compared with a two pilot CONOPS, an event or circumstance requiring communication with maintenance / dispatch during eMCO could result in higher workload for the pilot flying. The eMCO CONOPS envisions that the pilot flying will abort the eMCO segment if the workload is considered too high for a single pilot or if there is an unplanned event requiring substantial decision making.

Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context of the flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming controlling the aircraft.

Scenario ‘Event or circumstance requiring communication with cabin’

Note: Contingencies that may involve communication between flight and cabin crew are described separately under the scenario’s ‘cabin crew medical emergency’, ‘passenger medical emergency’, ‘pilot incapacitation’ and ‘security threat’.

Compared with a two pilot CONOPS, an event or circumstance requiring communication with the cabin during eMCO results in higher workload for the pilot flying. The eMCO CONOPS envisions that the pilot flying will abort the eMCO segment if the workload is considered too high for a single pilot or if there is an unplanned event requiring substantial decision making. Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context of the flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming controlling the aircraft.

In two-crew operations, frequent cabin crew checks can be used during controlled rest as a means to ensure that the non-resting flight crew member remains alert. In this case, the commander should inform the senior cabin crew member of the intention of the flight crew member to take controlled rest, and of the time of the end of that rest; frequent contact should be established between the non-resting flight crew member and the cabin crew by communication means, and the cabin crew should check that the resting flight crew member is awake at the end of the period (see EASA Rules for Air Operations, Annex IV (Part-CAT), Subpart B: Operating Procedures, GM1 CAT.OP.MPA.210 Crew members at stations, Mitigating Measures — Controlled Rest).

Regular cabin crew checks are also suggested by an OEM as a mitigation against negative effects of pilot incapacitation and impairment (particularly drowsiness). In addition, communication with cabin crew could also help to reduce boredom. During the simulator experiment on sleep inertia, fatigue and boredom (see project deliverable D-4.2 and 6.2), pilots flying reported feeling bored throughout the eMCO segment.

Scenario ‘deviation from target airspeed’

It is envisioned that during the eMCO segment the autopilot will be engaged at all times. A deviation from the target airspeed will therefore involve an autopilot disconnect, a wrong autopilot setting, an autopilot malfunction, or a combination of any of those events. Once detected, these events are expected to result in an immediate abort of the eMCO segment by the pilot flying. Meanwhile, immediate pilot response to restore the situation is necessary. In this specific scenario, additional flight deck effects resulting from the same underlying failure (particularly in case of an autopilot malfunction) may be possible. This may add to the pilot workload and make it more difficult for the pilot to recognise the correct procedure and act accordingly. In a single crew environment, there is no opportunity for cross-checking by the second crewmember. Furthermore, procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that supports the pilot in determining and cross-checking appropriate actions.

Scenario ‘deviation from target heading’

Deviation from target heading in this scenario refers to an unexpected and/or unplanned heading deviation. Expected or planned heading deviations are not part of this scenario. An unexpected or unplanned deviation from a target heading is an event that is expected to result in an immediate abort of the eMCO segment by the pilot flying. Meanwhile, pilot response to restore the situation is necessary. It can be expected that the pilot flying has more time available for diagnosis and assessment of appropriate actions than in the case of a ‘deviation from target airspeed’ scenario. In a single crew environment, there is no opportunity for cross-checking by the second crewmember. Procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that supports the pilot in determining and cross-checking appropriate actions.

Scenario ‘deviation from target altitude’

Deviation from target altitude in this scenario refers to an unexpected and/or unplanned altitude deviation. Expected or planned altitude deviations are not part of this scenario. An unexpected or unplanned deviation from a target altitude is an event that is expected to result in an immediate abort of the eMCO segment by the pilot flying. Meanwhile, pilot response to restore the situation is necessary. It can be expected that the pilot has more time available for diagnosis and assessment of appropriate actions than in the case of a ‘deviation from target airspeed’ scenario. In a single crew environment, there is no opportunity for cross-checking by the second crewmember. Procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that supports the pilot in determining and cross-checking appropriate actions.

Scenario 'deviation from target attitude'
It is envisioned that during the eMCO segment the autopilot will be engaged at all times. Once detected, a deviation from the target attitude is expected to result in an immediate abort of the eMCO segment by the pilot flying. Meanwhile, immediate pilot response to restore the situation is necessary. In this specific scenario, additional flight deck effects resulting from the same underlying failure (particularly in case of an autopilot malfunction) may be possible. This may add to the pilot workload and make it more difficult for the pilot to recognise the correct procedure and act accordingly. In a single crew environment, there is no opportunity for cross-checking by the second crewmember. Procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that supports the pilot in determining and cross-checking appropriate actions.

Scenario 'strategic deviation from airspeed/attitude/heading'
Strategic adjustments of airspeed, altitude and flight level may be required during cruise flight. Many of these adjustments are considered routine. Others might have been anticipated before the start of the eMCO segment resulting in a commonly agreed decision than only needs to be executed by the pilot flying. More complex or unanticipated situations might require substantial decision making and could require abort of the eMCO segment.

Absence of a second crewmember means that there is no cross-checking of flight crew decisions and actions by another pilot. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that provides a cross-checking function.

A situation that is too complex to be handled by a single pilot needs to be recognised and should result in the abortion of the eMCO segment. Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context of the flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to similar condition in a normal crew operations flight.

Scenario 'hazardous weather on flightpath'
Hazardous weather (e.g. thunderstorms) might require avoidance action by adjustment of the flightpath. Information on hazardous weather may be obtained from on-board systems (e.g. weather radar) but may also be given by ATC or weather information service providers. If the adjustment is considered routine or has been anticipated before the start of the eMCO segment resulting in a commonly agreed decision that only needs to be executed by the pilot flying, the adjustment can be performed under eMCO. More complex or unanticipated situations might require substantial decision making and could require abort of the eMCO segment.

Absence of a second crewmember means that there is no cross-checking of flight crew decisions and actions by another pilot. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that provides a cross-checking function.

A situation that is too complex to be handled by a single pilot needs to be recognised and should result in the abortion of the eMCO segment. Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to similar condition in a normal crew operations flight.

<u>Scenario 'restricted airspace on flightpath'</u>
Although most restricted airspaces will have been anticipated and accounted for during flight planning, there is a possibility that a particular circumstance results in acute and unanticipated closure of a certain part of airspace. This may need adjustment of the flight path and, because it is an unanticipated event, will involve some decision making that may require abort of the EMCO segment. Information on airspace restrictions will be provided by ATC or the airline's operation centre.

Absence of a second crewmember means that there is no cross-checking of flight crew decisions and actions by another pilot. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that provides a cross-checking function.

A situation that is too complex to be handled by a single pilot needs to be recognised and should result in the abortion of the eMCO segment. Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to similar condition in a normal crew operations flight.

<u>Scenario 'other aircraft on flight path'</u>
It is assumed that aircraft that are approved for eMCO are equipped with auto ACAS which allows the aircraft to automatically fly the correct resolution advisory (RA) manoeuvre if the autopilot is engaged. The pilot's task then is limited to monitoring the autopilot.

An unanticipated automatic ACAS manoeuvre can possibly surprise a pilot. The primary concern with surprises is that they generally interrupt an ongoing task (Rivera et al 2014). Compared with a two-pilot cockpit, during eMCO the principles of CRM cannot be used to mitigate the negative consequences of such a surprise.

<u>Scenario 'fire/smoke'</u>
Fire or smoke in the cockpit or in a location other than the cabin[2] will require immediate pilot action.

An on-board fire is one of the most stressful situations for a pilot. It is assumed that in case of a (suspected) fire the pilot resting is immediately alerted and may be instructed by the pilot flying to perform firefighting tasks, even if the resuming pilot is still suffering from sleep inertia. If the location of the fire is not immediately known (for instance when the only indication of a possible fire is a burning smell or visible smoke) the pilot first needs to take action to determine the location of the fire and isolate the affected system. To determine the location of a fire, the pilot usually needs to isolate a part of the system (typically electrical or air conditioning) and observe if this results in changes of the fire indications. Such 'if then' elements in a procedure increase workload. There may be a need to put on the oxygen mask and smoke goggles, which further increases workload.

[2] Smoke or fire in the cabin is expected to be addressed by the cabin crew. The flight crew is only expected to be involved if the situation cannot be controlled by the cabin crew.

If the location of the fire is known, the crew may try to extinguish the fire by discharging fixed or portable fire extinguishers, depending on the accessibility of the fire location and the location of the fixed fire extinguishing systems relative to the location of the fire. If these actions are not completely successful the flight crew must plan to land at the nearest suitable airport. This involves selecting an appropriate airport, checking local weather, and loading the arrival route into the FMS. It is assumed that in eMCO operations, diversion plans and suitable airports along the flight plan have been prepared pre-flight such that the amount of work required to initiate and execute the diversion is minimised. Future research is needed to provide evidence that workload and situational awareness are sufficient to assure an equivalent level of safety compared with normal crew operations.

Results from the simulator experiment on sleep inertia, fatigue and boredom (see project deliverables D-4.2 and D-6.2), showed no difference in crew performance responding to an engine fire during an eMCO segment in comparison with a non-eMCO segment, but also resulted in general feedback from participants that after an eMCO abort it is difficult to come together as a crew again. Immediately after an eMCO abort, crew resource management is therefore likely impaired, which might lead to reduced crew performance. The timing and contents of the transition briefing are therefore key factors for re-establishing effective CRM after an eMCO segment.

Scenario 'cabin crew medical emergency'

If during an eMCO segment a member of the cabin crew has a medical emergency, the first responders will be other cabin crew (if onboard) and passengers (if onboard and willing and capable of providing medical assistance). If the condition of the affected cabin crew member does not improve and appears to be critical, the pilot flying needs to be informed. The pilot will have to decide if the eMCO segment needs to be aborted and if immediate landing is required. The pilot may seek advice from medical professionals that are coincidental passengers on the flight, or from medical experts that can be contacted via the company operations centre. Especially when the condition of the cabin crew member changes rapidly (deterioration or improvement), the dynamics of the situation can bestow a significant amount of workload to the pilot flying.

Landing at the nearest suitable airport involves selecting an appropriate airport, checking local weather, and loading the arrival route into the FMS. It is assumed that in eMCO operations, diversion plans and suitable airports along the flight plan have been prepared pre-flight such that the amount of work required to initiate and execute the diversion is minimised. Future research is needed to provide evidence that workload and situational awareness are sufficient to assure an equivalent level of safety compared with normal crew operations.

Results from the simulator experiment on failure condition management (see project deliverable D-2.4) showed that pilots who anticipated an increase in workload in case of a developing medical issue in the cabin (in the case of the experiment it was a passenger medical issue), and decided to abort the eMCO segment early, experienced lower workload in comparison with pilots who aborted the eMCO segment later.

Results from the experiments on failure condition management also showed that one of the pilots who was confronted with a medical emergency in the cabin initially made an error in the selection of a diversion airport. Although this error was detected and corrected after the pilot resting had returned to the cockpit, this example shows the vulnerability of single pilot decision making.

Scenario 'passenger emergency'

If during an eMCO segment a passenger has a medical emergency, the first responders will be cabin crew and passengers (if willing and capable of providing medical assistance). If the condition of the affected passenger does not improve and appears to be critical, the pilot flying needs to be informed. The pilot may seek advice from medical professionals that are coincidental passengers on the flight, or from medical experts that can be contacted via the company operations centre. Especially when the condition of the passenger changes rapidly (deterioration or improvement), the dynamics of the situation can bestow a significant amount of workload to the pilot. The pilot will have to decide if the eMCO segment needs to be aborted and if immediate landing is required.

Landing at the nearest suitable airport involves selecting an appropriate airport, checking local weather, and loading the arrival route into the FMS. It is assumed that in eMCO operations, diversion plans and suitable airports along the flight plan have been prepared pre-flight such that the amount of work required to initiate and execute the diversion is minimised. Future research is needed to provide evidence that workload and situational awareness are sufficient to assure an equivalent level of safety compared with normal crew operations.

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Results from the experiments on failure condition management also showed that one of the pilots who was confronted with a medical emergency in the cabin initially made an error in the selection of a diversion airport. Although this error was detected and corrected after the pilot resting had returned to the cockpit, this shows the vulnerability of single pilot decision making.

<u>Scenario 'pilot flying incapacitation'</u>

Incapacitation of the pilot flying during the eMCO segment results in a situation where the aircraft is momentarily not controlled by a human pilot. It is possible that the pilot flying is able to self-detect a (gradual) incapacitation and alert the pilot resting. In the current multi-crew cockpit, pilots are trained to monitor each other for signs of (subtle) incapacitation. Total incapacitation is considered a major failure condition that will be clearly noticed by the colleague pilot, who will take action according to the instructions of the incapacitation procedures as trained in the incapacitation training of each ATPL pilot. An equivalent level of safety for eMCO requires a pilot monitoring system with a similar incapacitation detection and reaction performance as a fellow crewmember. A study in which subtle pilot incapacitation was simulated showed a range of 30 seconds to 4 minutes (average 1.5 minutes) before the pilot's condition was detected (Harper et al., 1971).

In eMCO, an on-board pilot monitoring system is expected to detect incapacitation of the pilot flying, alert the pilot resting and maintain the aircraft in a stable state until the pilot resting is able to take control of the aircraft. The monitoring system should be able to detect full incapacitation as well as subtle/partial incapacitation or impairment. OEMs that are developing aircraft for an eMCO CONOPS have indicated that eMCO aircraft will be equipped with pilot monitoring systems, without providing details of the composition of these systems nor of their capability to detect incapacitation. However, in order to be accepted by the pilot community, this system should be non-invasive, which means that techniques such as electrocardiography, electrooculography, electroencephalography and body thermometry cannot be used.

Pilot vigilance information may be obtained from (expected) pilot activity on the flight deck. However, during cruise flight there are relative long periods in which no pilot activity is expected. For a timely detection there might therefore be a need for a dedicated responsiveness challenge, similar to a dead-man's vigilance device used in rail transport. The design of such a monitoring system obviously requires careful considerations to avoid false positives, false negatives and to make sure there is no interference with other piloting tasks (Foot & Doniol-Shaw, 2008).

The online survey on pilot incapacitation that was distributed across the European pilot community (see project deliverable D-5) showed that fatigue was the most frequently mentioned type of incapacitation or impairment. Many respondents described that they had fallen asleep, had seen a crewmember fall asleep or had routinely experienced degraded performance due to fatigue. Results from the simulator experiment on sleep inertia, fatigue and boredom (see project deliverables D-4.2 and D-6.2) showed that 80% of the crews participating in the experiment reported high fatigue levels during the eMCO segment. Several pilots reported that they believed to have had micro-sleep episodes and were at times at risk of falling asleep. A literature study on pilot fatigue and performance (see project deliverable D-6.1) concluded that evidence-based information on the influence of being alone in the cockpit for an extended period of time is lacking.

Eye-related parameters such as blink duration, blink frequency and the Percentage of eyelid Closure (PERCLOS, Abe et al., 2023) can be measured non evasively with remote eye tracking and are considered for detection of drowsiness in aviation (Peissl et al., 2018). Whether these systems are sufficiently reliable in all possible operating conditions (including ambient lighting, use of (sun)glasses, etc) is questionable. Results from the investigation on pilot incapacitation management (see project deliverable D-5) concluded that at the time of this project there is not a single instrument available that is able to measure all aspects of incapacitation/impairment.

Cabin crew might have an active role in the means to detect pilot incapacitation. A procedure should then be in place where a member of the cabin crew regularly (e.g. every 15 minutes) enters the cockpit to check the pilot flying, similar to what is described in the current guidance material on controlled rest (GM1 CAT.OP.MPA.210 (f) (4) (iii)). While such a procedure can be effective to detect total incapacitation, it is less certain that subtle incapacitation (incoherent behaviour, etc.) would be detected. A list of check-questions can be envisioned, but effectivity may not be high if the same questions are asked routinely during each check. Effective CRM is required for such a procedure to be equally effective as cross-monitoring by a second pilot. Timeliness of incapacitation detection may also be an issue, as incapacitation will not be detected until the next check by cabin crew. Furthermore, checking by cabin crew is not an option for cargo flights with no cabin crew on-board.

Interference of the flight controls and aircraft systems by an incapacitated pilot must be prevented. The pilot resuming control of the flight will therefore need to divert the flight according to the procedures briefed at the start of the eMCO segment and inform ATC of the emergency situation.

Scenario ‘system malfunction’

In the basic risk assessment framework (see project deliverable D-1.2), the scenario for an aircraft system malfunction is generic for all systems (hydraulic, electric, etc.) with the exception of a fuel leak, aircraft depressurisation, unreliable air data and engine failure which are described as separate scenarios. A system malfunction will be detected by the pilot flying when prompted by the aircraft’s alerting system or due to secondary cues such as loss of system performance or unexpected system parameter values. The pilot flying will reconfigure the system as per the appropriate procedure (and prompted by the aircraft’s system display). Complex failures requiring substantial decision making or failures that result in significant loss of system performance may require abort of the eMCO segment.

The likelihood that a pilot (either in a single pilot or two-pilot situation) detects a system malfunction or irregularity is very much dependent on the failure manifestation. Failures that are not annunciated and result in abnormal or wrong data that is not a priori identified as out of range is most difficult to detect. For instance, incorrect position indication due to GPS spoofing. Detecting of these unannunciated abnormalities relies on the training, experience and alertness of the pilot.

Additional flight deck effects resulting from the same system malfunction may be possible. This may add to the pilot workload and make it more difficult for the pilot to recognise the correct procedure and act accordingly. In a single crew environment, there is no opportunity for cross-checking by the second crewmember. Procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that supports the pilot in determining and cross-checking appropriate actions.

If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to a similar condition in a normal crew operations flight.

Evidence is needed that workload and situational awareness are sufficient to assure an equivalent level of safety compared with normal crew operations.

Results from the experiments on failure condition management (see project deliverable D-2.4) showed that in the case of a complex simulated system failure during an eMCO segment workload of the pilot flying can become high, although much variation could be seen between crews. The availability of an autopilot function was considered to be a prerequisite for the pilot flying to be able to complete all recovery actions alone.

Results from the experiment also concluded that workload and error potential could be reduced if consequences of the system failure on aircraft performance are automatically transferred to the EFB so that any required performance calculation does not require additional manual input by the crew.

<u>Scenario ‘cabin depressurization’</u>
An aircraft depressurization will be detected by the pilot flying when prompted by the aircraft’s alerting system or due to secondary cues such as pressure on the ear or symptoms of hypoxia (e.g. blueness of the lips or fingertips, increased rate and depth of breathing). The immediate response of the pilot flying should be donning of the oxygen mask to prevent incapacitation due to hypoxia. It is assumed that eMCO suitable aircraft will automatically initiate an emergency descent in case of depressurization detected by the system. The pilot flying will have to establish communication with the pilot resting, monitor that the emergency descent is correctly executed by the aircraft systems and initiate the emergency descent if it has not yet been started by the aircraft systems.

The pilot resting needs to either don an oxygen mask and remain at the resting location until the aircraft has descended to a safe altitude, or use a portable oxygen mask and make his way to the cockpit without delay. In case of a rapid decompression it is essential for both pilots to put on an oxygen mask without any delay otherwise it is very likely that they will be incapacitated due to hypoxia. According to FAA Advisory Circular AC 61-107B[3], the time of useful consciousness following a rapid decompression at 35,000 ft altitude is typically between 15 to 30 seconds. For the pilot resting, this means that waking up, recognising the need to don a mask and the actual activity of donning a mask all have to be done within 15 seconds, while it can be expected that the pilot resting is impaired to some degree by sleep inertia, for which it is unclear if 15 seconds is feasible.

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[3] FAA. (2013) Aircraft operations at altitudes above 25,000 feet mean sea level or Mach numbers greater than 0.75. Advisory Circular 61-107B, Federal Aviation Administration

Scenario ‘fuel leak’

A fuel leak will be detected by the pilot flying when prompted by the aircraft’s alerting system, from monitoring fuel quantity values over time, or by a fuel imbalance. When the fuel leak has been detected, the location of the fuel leak may not be clear immediately. If the fuel leak is confirmed, the fuel leak procedure must be executed to mitigate the consequences of the fuel leak. A typical fuel leak procedure requires landing as soon as possible in case of a confirmed fuel leak. Absence of a second crewmember means that there is no cross-checking of flight crew decisions and actions by another pilot. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that provides a cross-checking function.

If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to similar condition in a normal crew operations flight.

Scenario ‘turbulence encounter’[4]

Turbulence encounter may be expected if it is known, e.g. from meteorological services or pilot reports, that there are areas of (clear air) turbulence on the flightpath, but an encounter with turbulence or a wake vortex can also be unexpected. When entering an (unexpected) area of turbulence, the pilot must switch the seatbelt sign ON and make an announcement to the cabin requesting passengers and crew to fasten seatbelts immediately. The pilot must inform the cabin crew when the aircraft is clear of the severe turbulence so that cabin crew can check for passenger injuries or any cabin damage. The cabin should then provide a cabin status to the pilot detailing the number of injuries and any cabin damage. Procedures may require disconnecting the autothrottle in case of excessive autothrottle variations.

Compared with a two pilot CONOPS, an encounter with severe turbulence during eMCO results in higher workload for the pilot flying. An unexpected severe encounter with clear air turbulence may startle and surprise the pilot flying. Procedures to mitigate startle and surprise will probably be different for a pilot flying without a second crewmember than for a normal two-pilot crew.

Seatbelts are used as a mitigating measure against the effects of an encounter with turbulence. It is therefore necessary that the pilot flying has fastened the seatbelts at all times during the eMCO segment. It will not possible for the pilot flying to momentarily stand up to stretch the legs. Depending on the duration of the eMCO segment this may be uncomfortable for the pilot flying and could initiate long term health effects. Long term air travel is known to increase the risk of venous thromboembolism (VTE) (Cannegieter et al., 2006). Although a cohort study amongst Dutch airline pilots concluded that the risk of VTE is not increased in current commercial airline pilots (Kuipers et al., 2014), the possible effect of pilot immobilisation during eMCO segments has not been studied yet.

Scenario ‘encounter with adverse weather conditions’

Adverse flight conditions may include weather, icing and volcanic ash. In many cases, regions with adverse weather conditions may have been identified during flight planning or during the flight, resulting in adjustment of the flight path (see scenario hazardous weather). Nevertheless, weather can be dynamic and it is still possible that a flight unexpectedly encounters hazardous weather conditions. Some adverse weather conditions may be difficult to detect, and once detected, the severity of the conditions may not be easy to

[4] The turbulence encounter scenario includes encounter with a wake vortex

assess. On-board aircraft systems are expected to support the pilot of an eMCO aircraft in the detection of adverse weather conditions. When a significant or non-obvious decision is required, it is expected that the eMCO segment will be aborted. Detailed criteria for the need to abort the eMCO segment cannot be given for this scenario, this will also depend on the context of the flight and the physiological and psychological state of the pilot flying. If the eMCO segment is aborted, the pilot resting will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to a similar condition in normal crew operations.

Scenario 'engine failure'

An engine failure may be associated with a variety of primary cues (engine alerts, engine parameter values) and secondary symptoms (noise, vibration, fire or smoke). The pilot must identify that an engine has failed, and then needs to identify which of the engines has failed. The aircraft systems are assumed to support the pilot decision making process by proper indications. After identification of the failed engine, the appropriate procedure, depending on the type of failure, must be executed. It is expected that the aircraft systems support the execution of the procedure by prompting the steps and providing hand guidance. Absence of a second crewmember means that there is no crosschecking of flight crew decisions and actions by another pilot. All else being equal, an equivalent level of safety for this scenario therefore requires an aircraft system or flight crew procedure that provides a cross-checking function.

In any case an engine failure will result in abortion of the eMCO segment and will almost always require the flight to descend to a lower flight level. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to a similar condition in normal crew operations.

Results from the simulator experiment on sleep inertia, fatigue and boredom (see project deliverables D-4.2 and D-6.2) showed no difference in the performance of crew performance in response to an engine fire in an aborted eMCO scenario compared to a non-aborted eMCO scenario. However, in the aborted eMCO scenario the engine fire was not the reason to abort the eMCO segment, and the pilot resting was already awake (albeit only for less than 3 minutes) and in the cockpit, when the engine fire occurred.

Scenario 'security threat (bomb on board, hijack, unruly passenger)'

A flight may encounter security threats such as (message of) a bomb on-board, a hijack and unruly passengers. These situations are very unpredictable, and therefore flight crew procedures are limited. The most frequent security threat is an unruly passenger. It is expected that unruly passengers are handled by the cabin crew and flight crew is only informed. Nevertheless, a situation with an unruly passenger may deteriorate to such an extent that the flight crew must be involved. In any case, a security threat that involves the flight crew requires abortion of the eMCO segment. If the eMCO segment is aborted, the second pilot will not be immediately available for active duty but must wait until the period of sleep inertia has ended and is appropriately briefed before resuming control of the aircraft. During this period, the workload for the pilot flying will be higher compared to a similar condition in normal crew operations. Depending on the location of the rest area, access of the pilot resting to the flight deck may be impeded in case of a security threat.

Cross-checking tasks

Many scenarios involve a cross-checking task. Cross-checking of the activities and decisions of one pilot by another pilot is one of the cornerstones of multi-crew principles. Cross-checking is a mitigating measure against slips, lapses and mistakes. During the eMCO segment, cross-checking by the second pilot is not possible. Alternative mitigating measures are therefore needed that provide at least the same level of protection against slips, lapses and mistakes as a cross-check by a second pilot. For a number of tasks that are predictable it can be envisioned that an aircraft system could perform some sort of cross-check, but with the current technology this is certainly not possible for all tasks and decisions. During an eMCO segment the pilot flying will therefore need to perform a self-check of tasks and decisions. While there are some tasks and decisions for which effective self-checking might be possible, an individual performing a self-check is obviously at risk of making errors.

During the experiments on failure condition management (see project deliverable D-2.4) almost all participant raised concerns about missing monitoring and cross-checking during the eMCO segment. During one of the scenarios the pilot flying made a mistake in selecting a diversion airport which was only corrected after the pilot resting returned to the cockpit and the FORDEC method was applied jointly by the pilots.

2.2 Conclusions from the application of the risk assessment framework

Based on the above in Chapter 2 the following conclusions were deduced.

<u>Preparation of eMCO flight</u>
Diversion plans and suitable airports along the flightpath should be prepared pre-flight such that the amount of work required to initiate and execute a diversion (decision) is minimised.

<u>Transition briefings</u>
The transitions from normal crew operations to eMCO and from eMCO to normal crew operations should only be done after the crew are adequately briefed to carry out their duties. The transition briefing should be supported by aircraft systems and sufficiently detailed procedures that allow systematic evaluation of relevant information. The transition from normal crew operations to eMCO should include a detailed evaluation of potential alternate airports and related weather during the eMCO segment. The transition briefing from eMCO to normal crew operations should be supported by aircraft systems that allow recovery of situational awareness by the pilot resting. The use of CPDLC could provide support to the pilot in regaining situational awareness. The timing and contents of the transition briefing are key factors for re-establishing effective CRM after an eMCO segment.

The transition briefing after an aborted eMCO segment should be performed only after immediate action items have been completed by the pilot flying and the pilot resting has sufficiently recovered from sleep inertia. While the pilot resting is recovering from sleep inertia, they should start self-synchronisation to build up situational awareness. Aircraft systems should support this self-synchronisation by providing summary information of the development of relevant aircraft and systems parameters over the past eMCO segment. The transition briefing should then be aimed at bringing the pilots together as a crew and supporting correct situational awareness of the crew.

<u>Procedures for sleep inertia</u>
The effects of sleep inertia have been shown to exits up to 35 minutes after awakening. The cognitive performance of a crewmember is impaired during the period of sleep inertia. The effects of sleep inertia on performance are assumed to dissipate exponentially with time after awakening. Because of impairment due to sleep inertia, the pilot resting should not be allowed to control the aircraft or be involved in decision making immediately after awakening. Adherence to a procedure that describes a fixed recovery time during which the pilot resting is not allowed to control the aircraft and be involved in decisions is expected to be low, particularly in case of an abnormal condition during the recovery period. However, self-assessment of sleep inertia is not accurate and may result in overestimation of the ability to perform. Face washing and exposure to noise/sound

are measures that could be considered to increase dissipation of sleep inertia effects, although further research into the effectivity of these measures for flight crew is necessary.

Incapacitation detection

eMCO aircraft should be equipped with a system and/or procedures to detect pilot incapacitation. The autoflight system should maintain safe control of the aircraft from the moment the incapacitation occurs up to the moment the pilot resting takes over control. The system and/or procedures should be able to detect full as well as partial incapacitation. The probability of sudden and complete incapacitation of commercial air transport pilots in the older age category (55-65) has been shown to be in the order of 1×10^{-6}. More than half of all incapacitation events cannot be predicted during periodical medical screening and are barely preventable. An equivalent level of safety for eMCO requires a pilot monitoring system with a similar incapacitation detection performance as a fellow crewmember. A simulation study suggested average detection time by a fellow crewmember of 90 seconds. An incapacitation detection system therefore should have similar performance characteristics.

Identified incapacitation detection systems within this project are often based on sensors that measure the state of the human operator. There is a wide variety of sensors such as camera systems, eye trackers, heart rate measurement systems and also systems to measure brain activity. This equipment is not sufficiently accurate to detect incapacitation with the same probability as a human (i.e. a co-pilot). The co-pilot can detect a broad range of incapacitation related behaviour. Examples are illogical inputs, eyes closing, sweating, changings skin colour. The co-pilot can also discuss these observations to retrieve more information from the presumably incapacitated pilot.

Further, intrusiveness (both physical as well as gathering more personal data) is likely not to be accepted by the pilot community. Alternatives such as a cabin crew member checking upon the pilot flying (while the other pilot is resting) could detect drowsiness or fatigue, but most probably at a later moment in time compared to the flight crew member who is constantly sitting next to the pilot flying, and is therefore automatically monitoring the pilot.

Also, an alternative such as an algorithm that can detect illogical pilot inputs into the aircraft's systems could detect those inputs at the moment that they are given, but during a long period (like and eMCO segment during the cruise phase) when no inputs are required, this approach will detect incapacitation later compared to normal crew operations.

Cross-checking

Cross-checking of the activities of one pilot by another pilot is one of the cornerstones of the multi-crew principle. For a number of predictable tasks it is envisioned that an aircraft system can perform a form of cross-checking, but this will not be possible in all relevant situations. Therefore, the pilot flying must perform a self-check of tasks and procedures during the eMCO segment. While there are some tasks and decisions for which effective self-checking might be possible, an individual performing a self-check is obviously at risk of making errors.

Surprise and interruption of ongoing tasks

On-board systems of eMCO aircraft should support situational awareness of the pilot flying in case of automatic manoeuvres and should support the execution of tasks by the pilot, particularly when task execution is interrupted by unforeseen events.

System failures

The availability of an autopilot function in the case of a system failure is a prerequisite for eMCO. Aircraft systems should support the execution of failure recovery procedures by prompting the steps and providing hand guidance. Workload and error potential can be reduced further if the consequences of a system failure on aircraft performance are automatically transferred to an EFB (or similar system) such that any required performance calculation does not require additional manual input by the crew.

Physiological needs

It is necessary that the pilot flying has fastened the lap belt at all times during the eMCO segment. It will not be possible for the pilot flying to visit the toilet or to momentarily stretch the legs. The average time in between toilet breaks of healthy pilots is a little more than 2 hours. A multitude of (medical) conditions regarding urination, defecation and menstruation can cause an increased (and uncontrollable) urge to go to the toilet more frequently (and longer) than anticipated. When the physiological urge is high, it might not be possible for the pilot flying to wait until the sleep inertia of the pilot flying has dissipated. This will lead to a condition where the pilot flying must be considered as incapacitated while the pilot resting is affected by some degree of sleep inertia.

3. Foreseen impact of eMCO

This impact analysis is based on a comparison between the current normal crew operations and the eMCO operations. The difference between both CONOPS will be considered, after which the impact the introduction of the eMCO concept on different aspects will be described. Four main impact categories are distinguished.

1. Economic: the financial costs and benefits, such as costs of implementation, savings, and revenue.
2. Social: the impacts on society, such as effects on employment, education or community well-being.
3. Safety: the probability and severity of incidents and accidents.
4. Environmental: impacts on the natural environment, climate change, and conservation of resources.

3.1 Economic

The economic costs of operating a fleet of aircraft may be divided into several categories. Publications by Eurocontrol (2024) and Doganis (1991) provide insight into which main categories should normally be taken into account. For the current study such an overview is useful in order to go through the different cost categories in a structured manner and to assess the potential cost categories that may be influenced by the eMCO CONOPS. Below an initial overview of the variable and fixed costs is shown.

Variable costs

- Fuel and oil
- Flight deck crew
    - Subsistence, bonusses and training
- Cabin crew
    - Subsistence, bonusses and training
- Engineering
    - Maintenance and overhaul
    - Related to flying hours and/or flying cycles
- Navigation charges
- Airport charges

- Aircraft acquisition or rental
- Passenger services
- Insurances

Fixed costs
- Aircraft standing charges
    - Depreciation or rental
    - Insurance
- Crew costs for flight crew as well as cabin crew (not connected to the amount of flying)
    - Uniforms, fixed salaries, administration, etc.
- Engineering and maintenance overhead
    - Fixed staff costs
    - Maintenance administration

By focussing on these different topics one by one, it was found that most of the categories will not be influenced by applying eMCO in the way that it is foreseen by the OEMs. An exception are the training costs (see also section 3.2).

Economic effects
In order to introduce eMCO costs will be made:
- More automation is needed to support the pilot when s/he is controlling the aircraft alone. Even though here is discussion possible about which automation is most needed or crucial. It is clear that more automation compared to normal crew operations with a crew of two will be needed. The most costly examples of investments in order to introduce eMCO comprise development of systems for:
    - Detection of incapacitation/impairment;
    - Keeping the aircraft in a safe envelope in case of pilot incapacitation;
    - Keeping workload at an acceptable level for a single pilot;
    - Supporting the regaining of situational awareness of the pilot returning and for coming together as a crew.
- New procedures are needed. For example, for the pre- and post eMCO briefings and for dealing with sleep inertia.
- For working according to new procedures and using new systems and functions that are introduced in the cockpit training will be needed.

Based on the results of this project, the assumption is that flight time limitation specified in Regulation EU No 1178/2011 will not be adjusted for the benefit of eMCO. If such changes were to be made (e.g. extending the maximum flight duty period for eMCO) economic benefits might be feasible, but indications that such adjustments are foreseen were not found, and such economic benefits are currently not expected.

3.2 Social

Social impact is the effect on factors like employment, education or community well-being.

The nature of the work of a pilot will change because the pilot will more often be flying alone while the other pilot is sleeping. This phenomenon is not new, because during controlled rest, or when one pilot needs to visit the toilet, the other pilot is also controlling the aircraft alone. However, during the eMCO periods, the pilot flying will be alone for a longer period of time compared to normal crew operations.

This will result in more opportunities for pilots to rest compared to the normal crew operations . Each eMCO segment is such an opportunity. Even, though there is no guarantee that the pilot will actually be sleeping and that there is no guarantee that the segment will not be aborted, in general at least the opportunity to sleep will increase. The question whether this results in reduced levels of (cumulative) fatigue or better rested pilots cannot be answered based upon the current study.

The introduction of changes to current Minimum Crew Operations (MCO) to include provision for eMCO will likely have an impact on current pilot training – both to the regulations, and to the aircrew training operations. The economic impact of the expected changes to the training are expected to be relatively small compared to the existing training costs – as this will be the cost of developing and scheduling training to address eMCO operations. This change is expected to include:

- Specialised Training or Acceptance: Regulatory authorities, or operators, may require pilots to undergo specific training programmes prior to approval to operate flights under eMCO procedures. Initially this would probably be focused on a small number of pilots who meet specific criteria based on the requirements of the operation.
- Recurrent Training and Checking: The existing requirements around training and checking are likely to require some modification and update to ensure that pilots maintain the necessary competencies to operate safely under the modified regulations. Existing recurrent training requirements for all flight crew involved in Minimum Crew Operations, or flights with augmented flight crew, may be updated to include provisions for eMCO procedures. Approved training organisations will be required to assess and where applicable update, their training content for potential changes to include either eMCO and/or SiPO requirements.
- Use of Flight Simulation Training Devices (FSTDs): The procedures associated with both eMCO and SiPO can be trained and assessed using current FSTDs with high fidelity flight deck environments. The realistic flight deck environment of these FSTDs enable pilots to train the individual procedures, as well as the hand-over and emergency procedures. Additionally, FSTDs may serve as a tool in the development and finalisation of the regulations, and then the procedures, associated with the operational changes.
- Competency-Based Training: EASA increasingly emphasises competency-based training and assessment (CBTA) and evidence-based training (EBT). This approach focuses on developing specific competencies required for safe operations, and including evidence into the training design, execution and assessment. While the impact of eMCO on the pilot competencies may be limited, the design of training, the syllabus design, for type and recurrent training, will likely be amended to take into account elements of the eMCO or SiPO concept of operations and procedures.
- Initial Multi-Crew Pilot Licence (MPL) Training: The MPL licence is focused on the training of ab-initio pilots for the multi-crew environment of the modern commercial airline operations through a competency-based training and assessment program. Any additional considerations for pilot competencies can therefore also be included in the MPL program to prepare pilots for the eMCO procedures.
- Single-Pilot Operations (SiPO) Training: In the event that eMCO is further developed to include SiPO, pilots will likely require additional training for the additional workload, and the modified responsibilities and procedures. This is likely to include advanced cockpit management, decision-making, as well as coordination with ground support services and systems. The training (and qualification) requirements for SiPO are likely to be higher than for eMCO, based on the risk assessment of the operations

3.3 Safety

In the safety analysis in Chapter 2 is described that there is a potential impact of eMCO on safety. The impact comprises the procedural aspects of eMCO such as:

- Flight preparation, where new and adjusted procedures are needed
- The briefings before and after an eMCO segment, in particular for aborted eMCO segments where a pilot might still be suffering from sleep inertia.
- The procedure for coping with sleep inertia, in particular whether it is realistic to assume that pilots will actually wait until sleep inertia is fully disappeared during an emergency.
- For pilot monitoring an equivalent level of safety for eMCO requires a similar incapacitation detection performance as a fellow crewmember. The systems that were identified in the current study are relatively slow and less accurate.
- A cross-checking function with at least similar performance as that of a second flight crew member.
- Procedures for failures of systems that need to be executed by one pilot under eMCO are not sufficiently compensated by automation or new systems to replace the role of the second pilot.

Clear solutions for all of the above-mentioned topics are not yet described. Until such descriptions are available, it cannot be assumed that eMCO can achieve an equivalent level of safety compared to normal crew operations.

3.4 Environment

Given the fact that the number of flights, the trajectories flown, and the periods when flight will take place are expected to remain the same during eMCO operations compared to normal crew operations, there is no impact on the environment expected.

4. Conclusion

The main question to be answered within this project is whether extended Minimum Crew Operations (eMCO) can be executed with an equivalent level of safety compared to the current operational concept, flying consistently with a crew of two in the cockpit. It was identified that there will be situations in which an equivalent level of safety cannot be demonstrated. Main areas for consideration are pilot incapacitation detection, cross-checking and sleep inertia.

Pilot incapacitation monitoring
In conventional two-crew operations, the remaining crew member can usually identify the pilot incapacitation issue relatively quick and accurate, assuming only one crew member becomes incapacitated at a time. Detection does depend on the type of incapacitation and the alertness of the non-incapacitated crew member. However, when incapacitation detection should rely on specific equipment, or pilot inputs into the flight systems, this detection is not yet considered sufficient – especially for partial or subtle incapacitation. The level of safety provided by current technological equipment that could be used to detect incapacitation does not yet seem to be equivalent to that of a human, such as a second pilot. Further, many sudden medical events that lead to incapacitation are impossible to prepare for, or predict. As a result, detection of incapacitation is likely to occur later in eMCO compared to normal two-person crew operations.

Fatigue and drowsiness
Regular cockpit checks by cabin crew can help mitigate the risks of pilot incapacitation or impairment, particularly for drowsiness or fatigue. These checks can also counteract boredom of the pilot flying. However, such checks are supportive and should always be combined with robust methods for effective detection of incapacitation and drowsiness. Cabin crew members might be too late to detect fatigue since they cannot monitor the pilot constantly.

Sleep inertia
Scientific literature shows that pilots may experience sleep inertia when waking up from their rest, and this state can last up to 35 minutes. However, it is unclear how the intensity and frequency of sleep inertia varies between individuals and situations. Because of this uncertainty, it is unclear what level of decision-making or operational actions can safely be expected from pilots during this period of sleep inertia. Therefore, clear guidelines need to be defined for pilot responsibilities, actions and expected decisions immediately after rest. These guidelines should cover a range of operations and conditions, from normal flight through to the various interrupted eMCO levels. The guidelines should also specify the types of information and decisions that can be safely processed by the waking pilot to maintain optimal crew performance.

Cross-checks
Cross-checking is a key safeguard against human error and has many forms during normal multi-crew operations. When a pilot is flying alone, however, the opportunity for cross-checking does not exist in the same way. Up until now no technological and procedural solutions have been identified to mitigate this limitation.

Physiological needs
A practical obstacle for eMCO is how the physiological needs of pilots during different eMCO circumstances will be addressed. A multitude of (medical) conditions regarding urination, defecation and menstruation can cause an increased (and uncontrollable) urge to go to the toilet more frequently (and longer) than anticipated. When the physiological urge is high, it might not be possible for the pilot flying to wait until the sleep inertia of the

pilot flying has dissipated. This will lead to a condition where the pilot flying must be considered as incapacitated while the pilot resting is affected by some degree of sleep inertia.

Impact
The impact of the change into eMCO is expected to be quite limited, although costs will have to be made before eMCO can become operational.

It is therefore concluded that an equivalent level of safety between eMCO and normal crew operations can currently not be demonstrated.

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Other official project deliverables

D-1.2 — Report on baseline risk framework for eMCOs
D-2.1 — Report on nominal operations
D-2.2 — Detailed research and test activity plan
D-2.6 — Nominal and Failure Condition Simulator Studies - Experimental Results

D-3 — Report on Failure Condition Management
D-4 — Report on the duration of sleep inertia
D-5 — Report on Pilot Incapacitation Management
D-6 — Report on Pilot Fatigue and Human Performance
D-6.2 — Ancillary report on Task 4 'Duration of sleep inertia' and Task 6 'Pilot fatigue and boredom'
D-7 — Report on solutions in relation to breaks due to physiological needs
D-8 – Report on the preliminary safety risk identification for SiPOs

These deliverables may be downloaded from: https://www.easa.europa.eu/en/research-projects/emco-sipo-extended-minimum-crew-operations-single-pilot-operations-safety-risk#group-downloads

Annex A eMCO Concept of Operations

The eMCO concept of operations that has been considered in this study focuses on extended Minimum Crew Operations within the current regulatory framework.

Extended Minimum-Crew Operations (eMCO) 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.

The concept that was investigated in the project's simulator experiments was based on an eMCO shift duration of 150 minutes, from the time that the pilot resting leaves the flight deck until their return (including waking, sleep inertia and an eMCO end briefing).

The design of the experiment in the project required conceptual eMCO procedures including the following items:

- Guidelines for the contents of the eMCO start- and the eMCO end-transition briefing
- A checklist for the eMCO prerequisites
- A list of the eMCO abortion criteria
- The sleep inertia recovery phase, defined by the 15 min time period in which the pilot resting was not allowed to take any action or participate in the decision-making process

Note that the contents of the transition briefing were based on transition briefings already applied to current long-range operations in case of crew member changes.

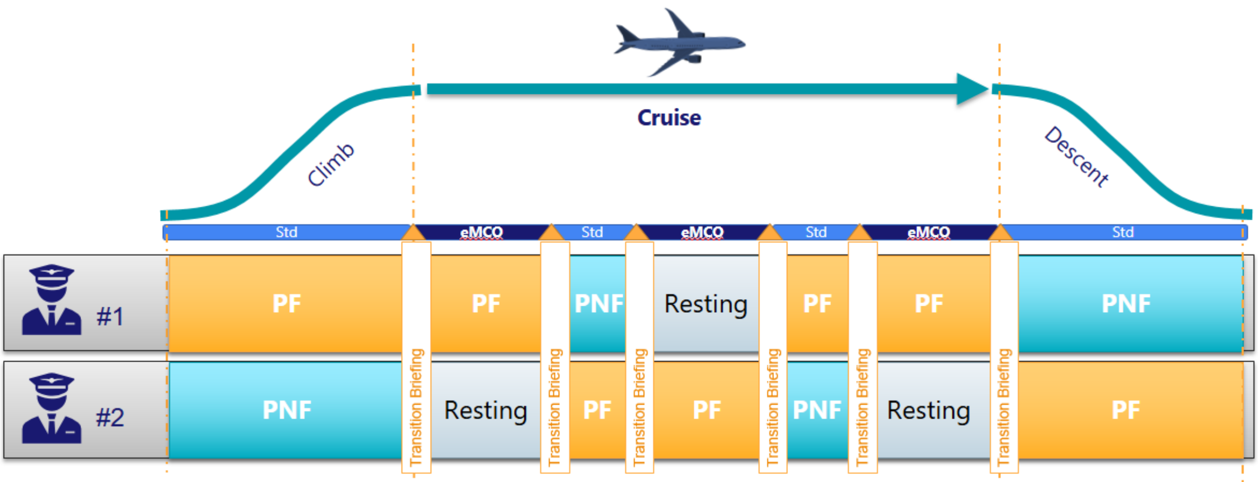

Figure 1 eMCO Concept of Operations - Flight Phases

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