Evaluation of operating procedures for single pilot incapacitation: Outcomes and insights from a real time simulation

Ana P. G. Martins, Teemu Joonas Lieb, Max Friedrich
German Aerospace Center
Braunschweig, Germany

Supathida Boonsong, Rickard Jorgensen
Luftfartsverket
Norrköping, Sweden

Gianmaria Mallozzi, Aurora De Bortoli Vizioli, Stefano Bonelli
Deep Blue
Rome, Italy

Andreas Triska
SWISS
Zurich, Switzerland

***Abstract*— A key enabler for the implementation of Single Pilot Operations (SPO) in commercial aviation will be to overcome the risks associated with single-pilot incapacitation. The SESAR JU project SAFELAND addressed this major challenge by proposing a concept of operations aiming at supporting flight and landing of a single-piloted CS-25 aircraft in case the on-board single pilot becomes incapacitated. In this paper, we describe the operational procedures and present the results of the Real Time Simulation (RTS) focused on the ground actors (mainly Air Traffic Controllers and Ground Station Operators). The RTS aimed to assess the impact of the SAFELAND concept on feasibility, acceptability, Human Performance and Safety. Overall, the RTS campaign returned positive evaluations. Participants positively evaluated the operating procedures, especially the dynamic of the interactions between team members, and to the coordination and communication flow. From the technical point of view, requirements for both the Ground Station and the Controller Working Position were identified, together with new additional supporting systems that should be implemented to enable SPO and enhance safety of the operations.**

Keywords: Real Time Simulation (RTS); Single Pilot Operations (SPO); pilot incapacitation; Air Traffic Management (ATM); Ground Station Operator (GSO)

I. Introduction

New operational procedures and technical innovations, in the cockpit and on the ground, are required before Single Pilot Operations (SPO) in commercial aviation can be implemented. Most concepts under investigation assume ground support by a Ground Station Operator (GSO) at all times to monitor and support the on-board Single Pilot (SP) from a ground station.

Following the concept proposed by [1], the operational concept developed in SAFELAND [2][3][4] assumes that SPO would be supported by three different ground stations positions: departure, cruise, and arrival. In nominal conditions, during departure and arrival phases, one GSO would assist one single pilot at a time, whereas in cruise (when workload is normally relatively low) the GSO would support several single pilots simultaneously. In the event of a full pilot incapacitation, the responsibility of managing the flight is transferred from the air to the ground, namely from the on-board pilot to the GSO.

If incapacitation takes place during departure or arrival, the GSO should already have an adequate mental picture of the aircraft (a/c) state and position at the moment of incapacitation and thus be able to assess the situation, then take over and land the emergency a/c. When incapacitation takes place en-route, the cruise GSO, who is supporting several pilots, takes over control of the affected aircraft but only until handing it over to a stand-by GSO. This dedicated stand-by GSO will be the one handling the emergency aircraft until landing.

The aim of this paper is to present the methods used and the results of the SAFELAND Real Time Simulation (RTS) campaign. Moreover, invaluable insights are provided on possible future research steps towards the implementation of SPO in commercial aviation. Further research in this regard has been undertaken by [5] when analyzing the tasks of a two-piloted cockpit and hereafter proposing supporting systems for SPO. Specifically, the *Pilot Monitoring and Recovery System,* capable of taking over command and control of the aircraft, is seen as technology to cope with single pilot incapacitation. In 2012, NASA hosted a technical meeting to collect input from aviation experts regarding Single Pilot Operations, with a special focus on how current tasks and responsibilities should be re-allocated [6]. Most participants agreed that SPO is feasible, and that pilot incapacitation is an important issue.

The SAFELAND RTS addressed Single Pilot Operations in the event of on-board Pilot Incapacitation with focus on the ground side, and on evaluating how incapacitation would be managed by Air Traffic Controllers (ATCOs) and GSOs. The RTS was one of several validation activities conducted within the SAFELAND project.

The objective of this human-in-the-loop simulation was to have relevant stakeholders experience the SAFELAND concept in a realistic situation, in order to get their feedback on the suggested operating procedures, as well as recommendations and requirements for future research. In this regard, considering the relatively low level of maturity and the exploratory nature of the project, the RTS focused on operational feasibility, human performance and safety aspects, and several assumptions were defined, both operational and technical.

Regarding operational assumptions, this RTS simulated a full incapacitation scenario in nominal flight conditions (e.g., no adverse weather) and all surrounding air traffic was datalink-equipped. That means all clearances given by the ATCOs were provided via datalink, except those for the emergency a/c, and consequently there were no read-backs or particular requests from other a/c sharing the same airspace. Regarding technical validation assumptions, it was decided to not investigate the malfunction of any system, including communication failures, and datalink was assumed to be adequate in terms of bandwidth and availability/stability. Furthermore, the project assumed the presence of technical support systems which are not currently available for commercial aircraft such as an on-board system monitoring the single-pilot health status throughout the flight and capable of detecting incapacitation, and an advanced system capable of autonomously landing the aircraft.

II. Methods and Materials

A. *Participants*

The RTS took place at the premises of the German Aerospace Center (DLR) - Institute of Flight Guidance and involved 10 participants: 5 ATCOs (two women) from *Luftfartsverket* (LFV) and 5 pilots (all men) from *SWISS* (performing the Approach or Stand-by GSO role) participated in the simulations. Each day, one ATCO and one pilot performed two runs: S01 and S02 (see next section).

Each morning, participants were welcomed and introduced to the experimental session with a briefing of around 30 minutes. The briefing covered an introduction to the SAFELAND concept and the participants' roles, responsibilities, and tasks during the RTS. In order to make the participants more familiar with the simulation platforms, a training session was also executed before the runs.

Before the RTS, participants signed an informed consent in line with the *General Data Protection Regulation* (GDPR).

B. *Simulation scenarios*

Two scenarios were simulated in the RTS: one scenario in Approach (S01) and one in Cruise (S02) (see Fig.1). In both scenarios, pilot incapacitation occurred a few minutes after the beginning of each run. In the first scenario the aircraft was flying from Zürich to Düsseldorf, with the run starting as the flight was about to enter the Terminal Maneuvering Area (TMA) of Düsseldorf at Flight Level 120. Thus, at the beginning of S01, the single-piloted aircraft was assisted by the Approach GSO. As soon as pilot incapacitation was detected and confirmed, the GSO took over control of the aircraft, and became the Pilot-in-Command (PIC) landing the aircraft at the nearest available airport. In the cruise scenario the flight was from Zürich to Kiev, crossing Hungarian airspace on the way, and the run started as the a/c was entering the Hungarian airspace at Flight Level 330. In this case, the aircraft was monitored by a Cruise GSO who was also supporting four other aircraft simultaneously. As soon as the on-board pilot incapacitation was detected and confirmed, the cruise GSO took over control of the aircraft and became the new Pilot In Command (PIC). At the same time, a Stand-by GSO was informed of the emergency and started to build-up Situational Awareness (e.g., checking aircraft's flight plan, current position, status of systems and subsystems, etc.). In a next step, the Cruise GSO handed over the control of the concerned aircraft to the stand-by GSO, who became the new PIC. The Stand-by GSO was then tasked to contact the Airline Operations Control Center (AOCC) for support on suitable diversion airports and land the aircraft safely from the Ground Station (GS). Weather and airport data from three different airports in the vicinity was provided to the GSO to facilitate decision-making.

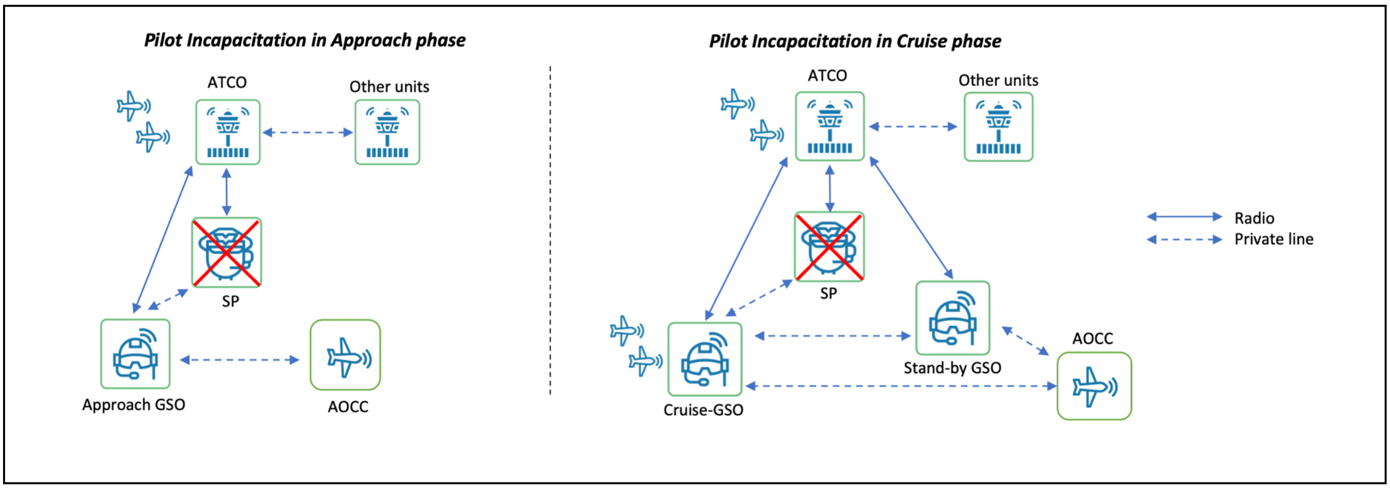

Figure 1: Simplified diagram of the SAFELAND architecture highlighting relevant actors and communication channels.

C. Roles, responsibilities and tasks

In the simulation, the following roles were covered:

- **on-board Single Pilot (S01 and S02)**, responsible for the safety of the flight, manages the a/c until incapacitation and handles communication and coordination with ATC and GSO as needed. This role was played by a consortium member.
- **Approach GSO (S01)**, supports the on-board pilot contributing to a safe and efficient flight during approach, and acting as the PIC after the on-board pilot becomes incapacitated. This role was played by a simulation participant.
- **Cruise GSO (S02)**, supports several single pilots during cruise, contributing to a safe and efficient flight, acting temporarily as PIC after pilot incapacitation until the aircraft is transferred to a Stand-by GSO. This role was played by a consortium member.
- **Stand-by GSO (S02)**, becomes the final PIC after receiving the emergency a/c from the Cruise GSO. This role was played by a simulation participant.
- **ATCO (S01 and S02)**, playing both approach and en-route ATCOs depending on the scenario, ensures air traffic operation and management. Responsibilities are not expected to change compared to current emergency operations. After incapacitation, the ATCO clears the airspace, supports the GSO as needed, and coordinates with any other ATC services/concerned units as needed. This role was played by a simulation participant.
- **All other ATC services/concerned units (S01 and S02)**, In case of an emergency and depending on the scenario, the ATCO on duty is expected to contact other sectors, emergency services, Supervisor, etc. All these roles were played by one member of the consortium standing next to the ATCO.
- **AOCC (S02)**, also played by one member of the consortium standing next to the GSO in S02, supports the stand-by GSO's decision on the most suitable airport to land the emergency aircraft. This actor had access to the same weather and airport information as the stand-by GSO.

All GSOs had an Emergency Checklist next to them describing the most important steps to be followed once the incapacitation alert is triggered. Table I provides a summary of those steps.

In terms of phraseology, participants were asked to use the current/standard phraseology between pilots and ATC as much as possible.

TABLE I. ROLES AND TASKS DURING THE RTS

Role	Tasks and Checklist steps after incapacitation alert
Approach GSO (S01)	• Contact a/c and confirm pilot incapacitation • Take over a/c control • Check a/c state and manage flight • Declare MAYDAY • Communicate control from ground • Coordinate with ATC
Cruise GSO [a] (S02)	• (…) *same first steps as for Approach GSO* • Communicate control from ground • Communicate start of handover process to ATC • Perform handover briefing with Stand-by GSO (incl. a/c position, Flight Level, Heading) • Acknowledge handover to Stand-by GSO • Coordinate with ATC
Stand-by GSO (S02)	• Check a/c state, flight plan/next waypoint (build SA) • Perform the handover briefing with Cruise GSO • Request and accept a/c control • Contact AOCC for support on suitable diversion airport • Report intentions to ATC • Manage flight, send new FPL • Coordinate with ATC

a. Member of the Consortium

D. Platform

The Institute of Flight Guidance at DLR provided the three different simulation platforms which were used in the RTS to simulate the controller working position (CWP), the ground station (GS) and the aircraft cockpit, located within the same facility in different rooms. The fully functional A321 cockpit simulator is integrated into the DLR simulation infrastructure and is based on X-Plane 11 software. Within this cockpit simulator, the primary flight control hardware consists of sidesticks, pedals, and flight control unit. Furthermore, five touchscreens enable the operation of interactive buttons, lights, knobs, and levels. Within the simulations, the surrounding air traffic was simulated via TrafficSim. TrafficSim is a sophisticated air traffic simulation that supplies all simulation tools with realistic aircraft data for all aircraft flying in a specific scenario. It simulates every aircraft as a single entity with its own performance, equipment, and capabilities. A radar display has been developed as part of the platform to support interaction by the air traffic controller via mouse and keyboard. It allowed the ATCO to visualize the actual position of each aircraft and aircraft control (i.e., altitude, heading, speed changes) via datalink as well as communication with pilots via headset. During the simulation, voice communications only occurred between the on-board single pilot, the GSO and the ATCO. This was because no pseudo-pilots participated in the RTS, thus all the other aircrafts were controlled by the ATCOs via datalink. The ground station software application U-FLY, developed by the Institute of Flight Guidance at DLR, is a human-machine interface (HMI) for the simultaneous supervision and guidance of multiple aircraft operated in controlled airspace. Its key features are the preparation, planning and creation of flight plans, and it has the possibility to provide navigation charts. Furthermore, this application enables remote access to autopilot function and aircraft configuration. Communication means to other actors (e.g. ATCO) are implemented as well. The U-FLY of the Approach and Stand-by GSOs showed only the data from the emergency a/c.

E. Data Gathering methods

Considering the exploratory nature and the low maturity of the project (V1) the assessment was mainly done through qualitative measurements. Data were gathered through (1) observations, (2) questionnaires and (3) semi-structured interviews.

During the simulation exercises, researchers observed participants' behavior to register any relevant aspects relative to their performance and any deviations from expected behavior. At the end of each experimental scenario, and at the end of the simulation session, participants filled out several questionnaires. The questionnaires consisted of close-ended statements that participants rated on a 1 to 5 scale of agreement, where 1 corresponded to "Strongly disagree" and 5 to "Strongly agree". After rating each item, participants had the possibility to explain their choice. The debriefing session at the end consisted of a semi-structured interview, where participants were invited to elaborate on different topics based on a prepared interview guideline. A final discussion session allowed participants to share any thoughts and opinions not yet covered and clarify possible ambiguities about the simulation and the concept experienced. Questionnaires and interviews' items covered all the investigated areas of Table II.

After the RTS campaign, the qualitative data collected were systematically merged, synthesized, and analyzed using standard research practices to ensure data reliability (i.e., *Thematic Analysis Methodology*). In the following subsections, results from the RTS campaign are reported according to the Validation Objectives specified in Table II.

TABLE II. VALIDATION OBJECTIVES AND INVESTIGATED AREAS

	Validation Objective	Investigated areas
VO1	Operational feasibility	• Feasibility • Acceptability
VO2	Human Performance	• Roles, Responsibility and Task Allocation • Operating Procedures • Team Structure and Communication • Situation Awareness • Workload • Technical Support Systems and Human-Machine Interface • Competence/Training Needs
VO3	Safety	• Safety hazards • Comparison with Current Operations • Possible Mitigations

III. RESULTS AND DISCUSSION

A. Operational Feasibility

Overall, at the current maturity level the SAFELAND concept of operations to address pilot incapacitation in SPO was perceived as acceptable by the involved participants, especially considering the operating procedures described in Table I and team communication and coordination. However, it was broadly agreed that its feasibility and further acceptability would be strictly dependent on future technological implementations, on the technical features and equipment reliability rate (e.g., datalink redundancy), and on the implementation of safety procedures and mitigation measures. Indeed, technological challenges, safety, cyber-security, and datalink issues were pointed out as the major possible technical showstoppers. In this regard, the round-trip latency between ground and air components using geostationary SATCOM satellites of approx. 1700 ms, is one major concern for future SPO [7]. Different technical solutions, as for instance, the 5G network or the multi-hop SATCOM technology have been proposed in order to decrease transmission times of command and control datalinks when controlling an aircraft from ground. In the case of the SATCOM technology this is ensured by allowing the usage of low earth orbit (LEO) satellites for these communication purposes [8]. The key benefits these satellites have over geostationary satellites in terms of latency is that they are at a lower altitude, which reduces the round-trip time of any C2 signal significantly. However, due to their increased proximity to earth, their coverage area is limited. This restriction can be overcome by using multi-hop solutions to build communication bridges between multiple LEO satellites that can transmit signals between themselves and thereby over great distances in a short period of time [9]. Besides that, datalink security is another key concern when relying on an aircraft being controlled from ground in case of pilot incapacitation. Further research in this domain needs to be undertaken before implementing SPO in commercial aviation. Nonetheless, the aforementioned aspects are naturally connected to the implementation of SPO for commercial aviation, which will constitute the framework on which the development of the SAFELAND Concept is based. Therefore, although the definition of nominal SPO procedures and SPO technical enablers was out of scope in SAFELAND, this simulation also brought up discussions around these topics.

B. Human Performance

1) Roles, Responsibility, and Task allocation

The 5 ATCOs' evaluation of the clarity and acceptability of their role and responsibilities as well as the clarity of the other actors' role, returned very positive results. These results are mostly due to the SAFELAND concept not envisioning any new or different ATCO procedures compared to current operations.

Looking at pilot participants, the majority of them understood their role and tasks, as well as those of the other actors involved in the concept (only one out of 5 pilots expressed a negative rating on the clarity of the GSO role, but this was mostly due to the technical issues encountered during that simulation session). However, some uncertainties during the exercise still occurred, due to the lack of familiarity with some details of the procedures and, in particular, the capabilities of the GS interface. Such unfamiliarity affected the decision-making process, meaning that some pilots were not always sure which actions and decisions were within their range of possibility.

Apart from the already mentioned technological enablers and safety requirements that would enhance pilots' acceptance, 3 of the pilots expressed a general concern regarding being alone in handling the emergency, without the possibility to share a mental model with a second pilot, as in current multi-pilot operations. They suggested that the support of a second GSO on the ground would mitigate this aspect. Moreover, 4 pilots lamented the feeling of not being in full control of the aircraft due to the lack of manual control possibilities, as most aviation tasks are being replaced by automation. For example, the GSO is only allowed to control the aircraft based on high level commands, such as heading, altitude or speed. Manual control, using throttle and stick to control the aircraft's control surfaces, is not foreseen in the concept due to latency issues. Such concerns explain the general low ratings given by the RTS pilots to the acceptability of task allocation between the GSO and the automation.

2) Operating Procedures

On ATCOs' side, the operating procedures experienced during the RTS campaign were considered clear and effective. When asked to compare their performance with current operations, answers returned a positive evaluation for the Monitoring, Conflict detection and resolution and Coordination tasks. The successful management of the emergency translated also in a global acceptability of the operating procedures envisioned by the concept since, as one ATCO affirmed during the debriefing, "*there was a very little difference from what we do on a daily basis*". On the other hand, pilots participating in the simulation campaign experienced a novel concept of operation entailing not only new procedures to be applied, but also a change in role (from on-board pilots to GSO), and a change in the operating environment (from a cockpit to a prototype of a GS).

Overall, pilots' evaluation of the procedures returned positive results. Many pilots defined them as straightforward, with some uncertainty only due to the lack of familiarity with the GS interface and not enough training on the new systems. One participant argued for clearer rules of engagement for the GSO (e.g., in case of a failure of the automatic incapacitation detection system). When asked to compare their ability to manage their tasks during the experienced scenarios versus current operations, the results were mixed. All 5 pilots positively evaluated the communication aspects with ATC, perceived as effective and not much different from current operations. The evaluation of other aspects, such as navigating and system management, was instead more affected by the limited possibilities of control provided by the GS and by the lack of information displayed on the GS interface (see section *6)* for a detailed discussion). This reaction was not surprising, considering the intrinsic differences between a cockpit and a GS, the constraints of the GS imposed by design, and the limitations of a simulation exercise. The procedures and the decision-making steps (described in Table I) were also considered effective. Nevertheless, one participant specified that, since in SAFELAND this process strongly depends on the automated systems in place, such systems should be as transparent and understandable as possible. Another participant pointed out that the ability to make decisions during the simulation was affected by the lack of information provided by the GS interface.

3) Team Structure and Communication

In the RTS exercise, communication aspects and team dynamics were very well evaluated by all the involved participants. Communication (i.e., between GSOs, between GSOs and ATCO, and between ATCO and the other ATC services/units) was defined as timely, clear, sufficient, and straightforward during all the flight phases. The level of information type and information quality provided by the different actors was considered adequate to perform the assigned tasks and handle the emergency, as well as the dynamic of interactions and the coordination between team members. One ATCO participant mentioned possible delays in communication as an important factor to be taken into account in real life operations.

Regarding team structure, 3 pilots expressed that the support of a second GSO on which to rely to make decisions and share the same mental model in case of on-board pilot incapacitation would increase the safe management of the flight from the ground. It is not excluded that such support in the future could be provided by a digital assistant [10] that, e.g., could help the GSO in monitoring the flight parameters, or provide a list of suitable diversion airports based on infrastructural, meteorological and airline operational conditions. By contrast, ATCO participants did not express any concerns on team structure. Looking at the interaction between them and the pilots, the replacement of the on-board pilot with a GSO was not perceived as affecting their performance and the achievement of their tasks. Nevertheless, more research is needed to explore in-depth the implications of this new interaction.

4) Situational Awareness

Pilot participants positively rated the information type and information quality provided to them by the other human actors involved in the simulations. Looking at the coordination between GSO and ATCO, the SAFELAND concept did not introduce many differences compared to the actual emergency procedures, therefore the information received from ATC corresponded to pilots' expectations. Considering the exchange between GSOs in the Cruise scenario, this consisted in the handover procedure, where the Cruise-GSO transfers the emergency aircraft to the Stand-by GSO. Despite the novelty of the process, all RTS pilot participants agreed that the information exchanged (i.e., aircraft position, next waypoint, Flight Level, souls on board) was satisfactory for them to perform their tasks. Nevertheless, for 3 pilots, the level of situational awareness experienced was affected by the limitation of the GS, specifically by the lack of information provided, and by the unfamiliarity with the console interface. Looking at the ATCOs' feedback after the RTS exercise, the rating on situational awareness also returned mixed results, but the trend was positive. In general, ATCOs considered the information provided by the CWP and by the other actors involved sufficient to handle the emergency. Some improvements to the HMI were suggested to increase the quantity/quality of the information provided (see section *f* for details).

5) Workload

The pilots' concerns regarding their high level of workload mostly depended on the missing and limited information provided by the GS, together with the perceived limited capabilities of the GS itself (i.e., lack of manual control possibilities). Also, the unfamiliarity with some procedures and with the HMI played a role, being the remote ground station a completely new environment for the pilots. Another contributing factor invoked by the majority of RTS participants to affect workload level was related with the characteristics of the GSO role, being the GSO responsible to evaluate the information, make the decision and then execute those decisions alone, with no possibility to cross-check the decisions with a second operator.

For the ATCOs participating in the RTS exercise, the workload level was considered acceptable, lower in the Cruise scenario than in the Approach scenario, due to their unfamiliarity with the approach procedures for Düsseldorf airport (this aspect is specific to the simulation exercise as in a real-life situation the ATCOs would be highly familiar with the airfield), and on the higher time criticality of the Approach phase compared to the Cruise phase. The other cause of high WL for 2 ATCOs was the technical malfunctions of the CWP software during the simulation.

6) Technical Support Systems and Human-Machine Interface

All pilots expressed concerns regarding the technical support systems and the human-machine interface of the GS. Those concerns covered limitations of the prototype used to simulate the GS, together with the new operation modalities envisioned by the SAFELAND concept. In this regard, most of the pilots commented that ideally the GS should replicate what there is in the real cockpit. Pilots recommended to have displayed on the GS (i) more information regarding the health status of the SP (a mere alert on the GS interface was not considered sufficient to understand the situation and make the right decisions), (ii) more information regarding the distance/time to the airports, and indication of distance/time to be flown between the waypoints to support decision on where to land (Cruise scenario) (iii) detailed analysis on the possibility to control the aircraft from the ground, instead of high level commands defined in SAFELAND concept. To mitigate those concerns, pilots identified possible additional technical support systems, including a shared audio environment as an option to have constant communication with the on-board pilot and directly assess health status, together with having the possibility to interact from the ground with the cabin crew. Another potential additional system often mentioned was a camera inside the cockpit. This would be beneficial to confirm the on-board pilot incapacitation, retrieve more information on the actual status of the pilot and, possibly, uncover the reasons for the incapacitation. Moreover, a camera could support the operations in the nominal case as well, giving the two pilots (on-board and on the ground) the possibility to see each other and the feeling of being a crew. Nevertheless, not every participant was comfortable with the idea of having a camera always on, suggesting a system that could be switched on "on request". Regarding concerns about the new operation modalities envisioned by the concept, two pilots lamented a lack of transparency and explainability of the automation. They pointed out the lack of real-time feedback from the aircraft automation together with a lack of manual control possibilities, with most of the tasks of the pilots being replaced by automation.

Also, some ATCOs identified improvements to the HMI to be included in future CWPs to enhance their situational awareness during SPO, as labels of different colors to underline the type of operations, and operational information automatically sent by the aircraft and displayed on the CWP (e.g., remaining fuel, numbers of souls on board etc.).

7) Competence/Training Needs

Four pilots and 3 ATCOs agreed that, to ensure a high level of safety, the GSO knowledge, skills and operational experience should be similar to those required for a pilot. Such expertise would be obviously combined with the specific training needed to operate remotely from a ground station position. Among the GSO competences, some participants pointed out the need for well-trained monitoring skills, necessary to accomplish a role that, apart from rare cases of active intervention, would be mostly passive. The other participants didn't express any opinion on this topic.

C. Safety

The feasibility of the SAFELAND concept strictly depends on the future implementation of safety procedures and mitigation measures that can guarantee the same (or higher) safety levels compared to current multi-pilot operations, together with a system that in the future should be redundant.

During the debriefing session, simulation participants were asked to identify potential hazards for the concept together with possible mitigation solutions. Among technical hazards, they mentioned engine failure, automation failure, and other technical failures that currently cannot be addressed from the ground since they need a physical intervention on the aircraft. Regarding communication, the main risks addressed were the loss of data link between the GSO and the aircraft, failure of other communication means, and communication latency. Other hazards pointed out were adverse weather (e.g., windshear, severe turbulence) and fire on board.

As for potential mitigations procedures, according to both pilots and ATCOs, advanced automation capabilities would need to cover most of the hazards that might happen during single pilot incapacitation, as for example systems to make the aircraft able to autonomously follow the flight plan and land automatically without any input from ground or have multiple data link connections to create redundancy.

An additional threat mentioned by some participants was connected to the capabilities of the pilot incapacitation detection system. In fact, it was argued that not every type of incapacitation can be detected through the monitoring of physiological parameters, and a non-detected subtle incapacitation might jeopardize the flight as well. To mitigate this, participants highlighted the importance of being able to communicate with the on-board pilot and cabin crew members during the flight. Cyber security risks were also mentioned by a participant as a source of possible hazard, the main concern being the risk of a possible external hostile takeover of the aircraft through the GS. To mitigate this, multiple stable connections are required between the GS and the aircraft.

Participants also identified situations that might lead to human errors. As said, not sharing the mental model with a second person while handling the emergency might affect the effectiveness of the decision-making process and increase the likelihood of errors, leading to hazardous situations. As a mitigation, participants suggested that having a second person on the ground supporting the GSO could limit the possibility for human errors. In general, it was argued that working in a team with other actors would increase the safety of the flight. Other possibilities for human errors can result from the GSO not being physically located inside the aircraft. Being on the ground, the GSO lacks the sensory cues that normally improve the pilot awareness of the aircraft status and of the operating environment. Possible mitigations include additional technological systems already mentioned as cameras and microphones on board, allowing to share the cockpit environment with the GS, and operational aspects, such as the introduction of a second GSO to better monitor the aircraft parameters during an emergency. In terms of GSO competencies, it was broadly recognized that having a GSO who is a certified pilot would highly increase the safety of operations.

IV. Conclusions and Next Steps

Overall, the RTS campaign returned a positive evaluation of the SAFELAND concept of operations (CONOPS), with some issues mostly related to the technology in place. Most importantly, the involved participants positively evaluated the operating procedures, especially referring to the dynamic of interactions between team members, and to the coordination and communication flow.

Pilot participants had to deal with a large amount of changes (both procedural and technical) introduced by the concept. First, at the operational level, pilots were introduced to a new environment (the GS) and to a completely different modality of operation (e.g., no manual control of the aircraft). Moreover, they faced a change in their role and responsibilities when they were asked to handle the emergency alone as single remote pilots. Second, from the technical point of view, they were asked to rely on new systems and technologies presented at a conceptual level, or still not implemented in civil aviation (e.g., the pilot health monitoring system, the autonomous landing system), and on assumptions (e.g., reliability and redundancy of the datalink, no other failures). Third, they were invited to experience and evaluate a non-nominal case (single-pilot incapacitation) of a not yet adopted concept of operations (i.e., SPO in commercial aviation). These aspects had a major impact on pilots' assessment, especially considering the evaluation of the technology in place in relation to the tasks to be accomplished, safety aspects and a general trust in the concept. Most of these aspects are only partially connected with the SAFELAND concept itself, being in fact much more related to the implementation of SPO for commercial aviation. Further research is needed to uncover whether the procedures envisioned by SAFELAND will be compatible and applicable to the broader SPO CONOPS, and to what extent improvement in technology will support the SAFELAND concept. In that sense, it is recommended that a reference SPO CONOPS should be adopted to provide a framework for future research in single-pilot incapacitation. For instance, the management of the incapacitation can be affected by the flight context and thus, by the nominal SPO concept adopted. This reference nominal SPO concept should not impede other approaches to develop, but it would promote harmonization of requirements and ensure an understanding of each challenge in a holistic way. It is straightforward that the development of a definitive SPO CONOPS will proceed in parallel with the progression of the key technological enablers needed to preserve the same safety levels of current operations (e.g., a fully integrated health monitoring system, autoland capabilities, back-up systems). Features of these systems are based on past and ongoing research, with some additional requirements that make these potential solutions applicable to the SAFELAND concept.

During the development process of the concept (through workshops), the consortium came to the conclusion that the introduction of substantial changes in the ATC procedures was not necessary. Therefore, in SAFELAND, pilot incapacitation was treated by ATC like any other emergency and the SAFELAND concept was globally found acceptable and feasible by the five ATCOs participating in the simulation. However, only full incapacitation in “nominal cases" was tested (e.g., no additional failures, no partial incapacitation assessment) and assuming strong requirements in terms of technical features and equipment rate (e.g., a reliable datalink with enough bandwidth and no latency). Therefore, additional use cases and unexpected events need to be assessed for further maturing the concept, such as late go-around, change of destination airport, or possible failures induced by the new systems. Furthermore, the SAFELAND project only focused on a limited scope: i.e., from incapacitation confirmation until landing. Further assessment may be needed to address a larger scope, such as a longer transition period from nominal SPO case (on-board pilot in control) to incapacitation confirmation, ground handling, partial and temporary incapacitation, and the role of the cabin crew. Finally, further research is needed regarding social and ethical aspects, such as trust and confidence, as well as acceptability regarding public, Trade Unions, and pilot organizations.

As already mentioned, pilots’ evaluation of the SAFELAND concept was greatly influenced by the characteristics of the GS and the HMI, although the main focus of the simulation was the assessment of a concept of operations and not of the technical systems. This aspect could be overcome by exposing participants to longer training sessions with the GS and the new technical systems in place. It is clear that longer briefing and training sessions would imply other problems, from the organizational and economic point of view.

Another major obstacle for the tested pilots was represented by the effort required to step into the role of a remote pilot working as a single pilot on the ground. Many of them did not feel comfortable in managing the situation alone, being used to working in a team of two. Although this represents valuable feedback, it would be interesting to test the concept with pilots used to different types of operations, such as single-pilots or drone pilots.

The observation of ATCOs' behavior during the tests did not reveal major issues, confirming the global positive assessment given by the participants. The few difficulties encountered were mostly related to the technical malfunctions experienced during the simulation, and to the participants' unfamiliarity with the airspace. Therefore, to improve the facility and authenticity of the simulation, participants should be exposed to the airspace they are familiar with (in our case, since the ATCOs were recruited from LFV, the Swedish airspace). Also, having the same ATCO performing both the approach and the en-route role in the two different scenarios could have been a potential difficulty. However, this fact was not mentioned by our participants, revealing that a certain degree of freedom can be still kept during the simulations.

ACKNOWLEDGMENT

This work has been performed in SAFELAND, a project that has received funding from the European Union's Horizon 2020 SESAR Research and Innovation action under Grant agreement No 890599.

The authors would like to thank Thomas Dautermann, Helge Lenz, Gunnar Schwoch and Matthias Wies for their help during the RTS.

V. REFERENCES

[1] Schmid, D., & Korn, B. (2017). A tripartite concept of a remote-copilot center for commercial single-pilot operations. In *AIAA Information Systems-AIAA Infotech@ Aerospace* (p. 0064).

[2] Paz Goncalves Martins, A., Lieb, J., Friedrich, M., Bonelli, S., Celori, M., & De Bortoli Vizioli, A. (2021). Toward single pilot operations: A conceptual framework to manage in-flight incapacitation. 11th SESAR Innovation Days: Inspiring Long-Term Research in the Field of Air Traffic Management, SIDs 2021.

[3] Paz Goncalves Martins, A., Lieb, J., & Friedrich, M. (2022). The Ground Station Operator in Single Pilot Operations. Active or Passive role? *Advances in Transportation*, Vol. 60, 2022, 1–7. AHFE 2022

[4] SAFELAND Project (2021). Final Concept. SAFELAND D1.4. https://safeland-project.eu/sites/default/files/2021-06/SAFELAND_D1.4_Final_Concept.pdf

[5] Norman, R. M. (2007). Flight Critical Systems Research - Economic Opportunities and Technological Challenges For Reduced Crew Operations. The Boeing Company. Contract NNL06AA04B. 48 pp.

[6] Comerford, D., Brandt, S. L., Lachter, J., Wu, S.-C., Mogford, R., Battiste, V. and Johnson, W. W. (2013). NASA's Single-Pilot Operations Technical Interchange. Meeting: Proceedings and Findings. Moffett Field, CA, USA.

[7] Nederlandse Organisatie voor toegepast-natuurwetenschappelijk onderzoek (TNO) (2005). UAVs and Control Delays. Soesterberg, Netherlands

[8] Zolanvari, M., Jain R. and Salman, T. (2020). "Potential Data Link Candidates for Civilian Unmanned Aircraft Systems: A Survey," in IEEE Communications Surveys & Tutorials, vol. 22, no. 1, pp. 292-319, doi: 10.1109/COMST.2019.2960366

[9] Soret, B., Ravikanti, S., Popovski, P. (2020). Latency and timeliness in multi-hop satellite networks. ICC 2020 - 2020 IEEE International Conference on Communications (ICC), 2020, pp. 1-6, doi: 10.1109/ICC40277.2020.9149009.

[10] Minaskan, N., Pagani, A., Dormoy, C. A., Andre, J. M., & Stricker, D. (2021, October). A Study of Human-Machine Teaming For Single Pilot Operation with Augmented Reality. In 2021 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct) (pp. 397-402). IEEE.