Integration Report

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SAFELAND

SAFE LANDING THROUGH ENHANCED GROUND SUPPORT

This deliverable is part of a project that has received funding from the SESAR Joint Undertaking under grant agreement No 890599 under European Union's Horizon 2020 research and innovation programme.

Abstract

This deliverable includes two parts: Part 1 and Part 2.

Part 1 – *Integration Report* describes the simulation environment and details the integration efforts for setting up the real-time simulation (RTS) within the SAFELAND project. The RTS will be conducted at DLR´s Institute of Flight Guidance in Braunschweig, Germany and will take place in the first week of May 2022 involving experienced ATPL pilots and Air Traffic Controllers, Legal and regulatory experts as well as Human Factors experts.

This deliverable, as initially planned, would describe the final architecture of the simulators at DLR and EUROCONTROL, specifying the interactions specifications between them. However, travel restrictions in 2021 and uncertainties imposed by the COVID-19 situation forced the consortium to decide to move all simulations to a single location, in this case DLR. Consequently, D2.4 will describe the integration of the different components allowing the execution of the SAFELAND simulations, but only at DLR.

In particular, the simulation scenarios for evaluating the operational SAFELAND concept for handling pilot incapacitation in single pilot operations, the used simulation architecture including the voice communication architecture between the simulation participants, as well as the required simulators are described in this report.

Part 2 – *Low Fidelity Simulation* contains the description and results of the SAFELAND Low-Fidelity Simulation (LFS) exercises held online between November and December 2021. The LFS aimed to provide a first evaluation of the feasibility and validity of the SAFELAND concept, with a focus on specific aspects such as roles, procedures, communication, and human-automation interaction. The SAFELAND LFS was developed in collaboration with the H2020 RIA project SAFEMODE

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Part 1 – Integration Report - Introduction[1]

1.1 Purpose and scope of this document

The main goal of WP2 is to prepare the setup of the real-time simulation exercise based on the work done in WP1. Initially, as described in the Proposal of Work (SAFELAND, 2019), the ATC/CWP simulator would be provided by EUROCONTROL, whereas the cockpit and remote pilot (ground station) simulators would be provided by DLR. However, travel restrictions in 2021 and uncertainties imposed by the COVID-19 situation forced the consortium to decide to move all simulations to a single location, in this case DLR.

In its current form D2.4 – Integration Report (the outcome of T2.4) will describe the integration of the different components, the setup of a configuration and the connections allowing the execution of the SAFELAND evaluations, but only at DLR. As will be described below in more detail, the CWP, Cockpit and Remote Cockpit simulators have been adapted for the SAFELAND simulation exercise, integrating the functions foreseen in T1.4.

1.2 Structure of the document

In total, Part 1 – *Integration Report* consists of 8 chapters, which are further subdivided into subsections. The chapters and their main topics are the following:

- Chapter 1 introduces Part 1.
- Chapter 2 gives a description of the simulation scenarios.
- Chapter 3 explains the Simulation Architecture and Communication Infrastructure.
- Chapter 4 describes the Simulators as well as required software tools.
- Chapter 5 provides the description of the simulation data that will be exchanged between the different simulators.
- Chapter 6 describes the simulation data to be collected.
- Chapter 7 presents the results of the Integration test sessions.
- Chapter 12 lists the references used in this document.

[1] The opinions expressed herein reflect the author's view only. Under no circumstances shall the SESAR Joint Undertaking be responsible for any use that may be made of the information contained herein

1.3 List of acronyms

Term	Definition
A/C	Aircraft
ASV	Aircraft State Vector
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATM	Air Traffic Management
CWP	Controller Working Position
FPL	Flight Plan
GCS	Ground Control Station
GSO	Ground Station Operator
PF	Pilot Flying
PIC	Pilot in Command
PTT	Push-To-Talk
SJU	SESAR Joint Undertaking
SP	Single Pilot
SPO	Single Pilot Operations
TMA	Terminal Manoeuvring Area
RTS	Real-time simulations
VoIP	Voice over Internet Protocol

Table 1. Acronyms

2 Simulation scenarios

In order to develop and prepare the simulation environment in an optimal way for the real-time simulations (RTS) within the SAFELAND project, the agreed simulation scenarios will have to be examined and verified for their operability in the proposed simulation facilities. The dependencies between the simulation environment and simulation scenarios has to be determined in detail.

As described in deliverable D3.1 (SAFELAND Project, 2021a), the SAFELAND consortium agreed to simulate two different types of scenarios in order to evaluate the various aspects of the proposed concept, and to stress the concept in several flight phases. One scenario (i.e. S01) will simulate single pilot incapacitation in a commercial large passenger aircraft (i.e. A321 aircraft model) during cruise in the en-route phase of the flight. The other scenario (i.e. S02) will contain single pilot incapacitation in a commercial large passenger aircraft during approach within the Terminal Manoeuvring Area (TMA) of an airport. Both scenarios will be conducted as human-in-the-loop (HITL) exercises involving airline pilots and air traffic controllers.

In reference to deliverable D3.1 Table 2 depicts the envisaged simulation scenarios on high-level.

	Description	Incapacitation	Starting Phase	Ending Phase	Contextual conditions
S01	Short flight over Europe	Full pilot incapacitation	En-route	After decision on alternate airport	No technical failures Normal traffic and weather conditions
S02	Short flight over Europe	Full pilot incapacitation	Approach, right before entering the TMA	Touch down	No technical failures Normal traffic and weather conditions

Table 2. High-level scenario description

The implication on the simulation environment for these two different types of scenarios will be described in section 2.1 and 2.2 individually.

2.1 S01 – Single Pilot incapacitation during cruise

In general, within S01 of the SAFELAND RTS pilot incapacitation will occur during cruise in Hungarian airspace and involves the following roles that will have to be simulated:

- A single piloted aircraft simulated via the cockpit simulator iSIM
- A cruise GSO monitoring five aircraft simultaneously via the Ground Control Station U-FLY, whereby in one of them single pilot incapacitation will be detected.
- A stand-by GSO available to take over control of an concerned aircraft via a second entity of the Ground Control Station U-FLY from the cruise GSO

- An en-route ATCO monitoring the relevant sector via his/ her CWP when pilot incapacitation occurs

Figure 1 illustrates the high-level process and procedures that will take place within S01.

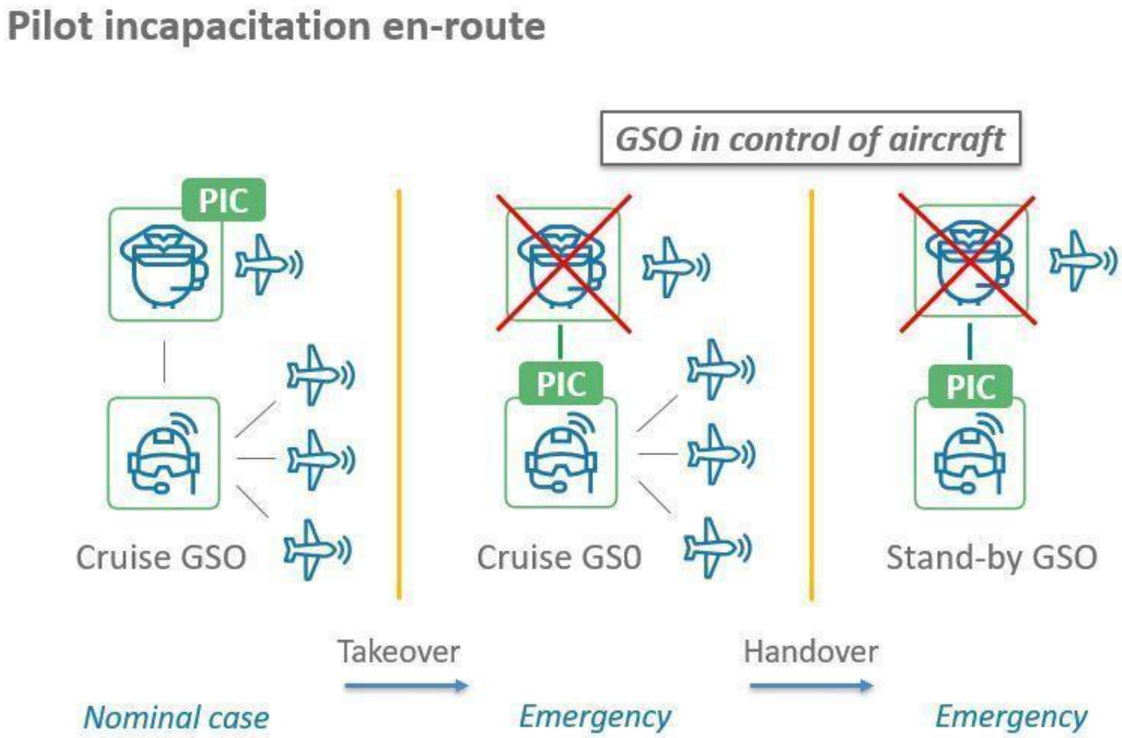

Figure 1. High-level illustration of the SAFELAND concept for pilot incapacitation during cruise

At first, the single piloted aircraft is controlled by the pilot onboard of the aircraft and monitored by a cruise GSO. In addition, this cruise GSO is monitoring four other aircraft from his/her airline organisation (cf. Figure 1, left). Moreover, throughout the entire scenario a stand-by GSO is monitoring the situation and an en-route ATCO is managing the traffic. As soon as onboard pilot incapacitation is detected and confirmed, the cruise GSO will take over control of the aircraft and become the new PIC (cf. Figure 1, middle) of the concerned aircraft. At the same time, the stand-by GSO will be informed of the emergency and starts to build-up situational awareness (e.g. check aircraft´s FPL, its current position, check aircraft status, etc.) of the entire event. In a next high-level step, the cruise GSO will hand over the control of the concerned aircraft to the stand-by GSO, who will become the new PIC (cf. Figure 1, right). This handover is required as the cruise GSO is monitoring several aircraft simultaneously and cannot focus his/her attention to the concerned aircraft as it would be required. The stand-by GSO is now asked to take over the tasks of the single pilot (as described in D1.4 (SAFELAND, 2021a) and land the aircraft safely. Throughout the entire event, coordination (e.g. via verbal communication) between the involved actors (SP, cruise GSO, stand-by GSO, en-route ATCO) is expected.

2.2 S02 – Single Pilot incapacitation in TMA

Within S02 of the SAFELAND RTS pilot incapacitation will occur during approach of the aircraft within the TMA of Düsseldorf airport (EDDL) and involves the following roles that will have to be simulated:

- A single piloted aircraft simulated via the cockpit simulator iSIM
- An approach GSO monitoring the one aircraft in which single pilot incapacitation will be detected via the Remote Pilot Station U-FLY. After the pilot incapacitation is confirmed the approach GSO will become the Pilot-in-Command (PIC)
- An approach ATCO managing and monitoring the relevant sector via his/ her CWP (in which pilot incapacitation will occur)

Figure 2 illustrates the high-level process and procedures that will take place within S02.

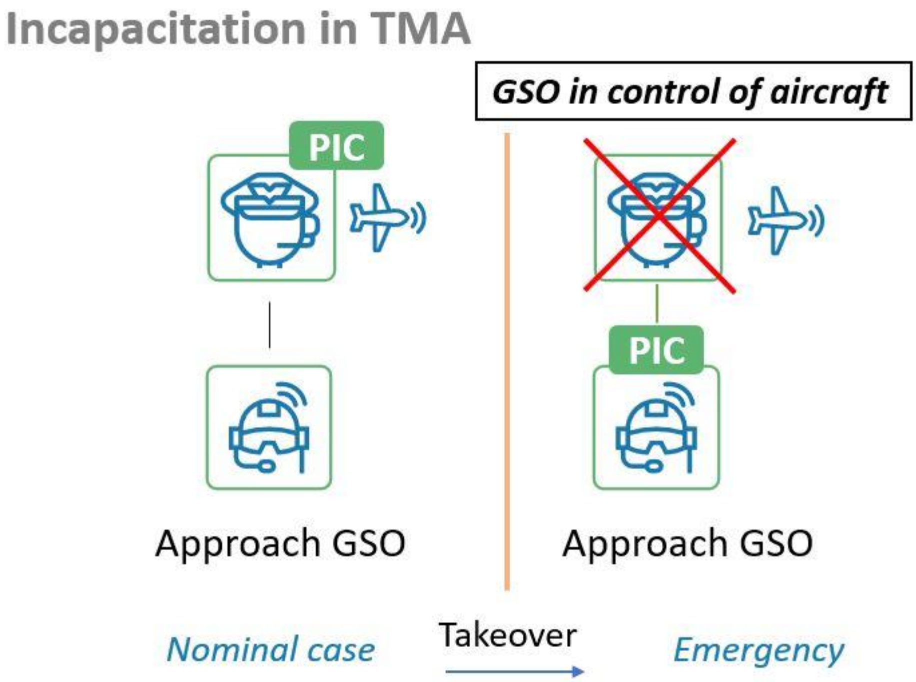

Figure 2. High-level illustration of the SAFELAND concept for pilot incapacitation within TMA

At the beginning of S02, the single piloted aircraft will be controlled by the pilot onboard of the aircraft and monitored by an approach GSO (cf. Figure 2, left). In addition, throughout the entire scenario an approach ATCO is monitoring the situation. As soon as onboard pilot incapacitation is detected and confirmed, the approach GSO will take over control of the aircraft, and become the new PIC (cf. Figure 2, right). The approach GSO will take over the tasks of the single pilot (as described in D1.4 (SAFELAND, 2021a) and land the aircraft safely.

3 Architecture

The RTS will take place at DLR´s Institute of Flight Guidance in Braunschweig, Germany. The required simulators and the simulation environment are located within the same facility in different simulator rooms. In order to facilitate the SAFELAND RTS, the Institute of Flight Guidance offers several simulators that can be interconnected and support real-time and human-in-the-loop simulations. Each of the individual simulators provides workplaces for human operators and have been adapted for the SAFELAND use cases. Depending on the conducted scenario (cf. chapter 2) different simulators and working positions will be interconnected. In the following subsections (i.e. chapter 3.1.1 and 3.1.2) a detailed view on the interconnected simulators and required human working positions will be given.

3.1 Simulation architecture

Figure 3 illustrates the simulation architecture for S01 with the en-route flight over Hungarian airspace for nominal operation, and in case of onboard single pilot incapacitation. The figure details the data types that will be exchanged between the different simulators for both scenarios. Hereby it visualises the interconnection in the developed simulation environment where *Datapool* is the main distribution tool for the messages used in the simulation. More details on the simulation tools (e.g. datapool, TrafficSim), and the various data types including the transmitted messages will be given in section 4 and 5.

Figure 4 clarifies the simulation architecture for S02 with the aircraft approaching the Düsseldorf airport (EDDL) for the nominal operation, and in case of pilot incapacitation. The figure shows which actors are expected to be involved in S02 and which data types are foreseen to be transferred between the simulators. More details on the specific messages within each data type will be given in section 5.

3.1.1 S01 – simulation architecture

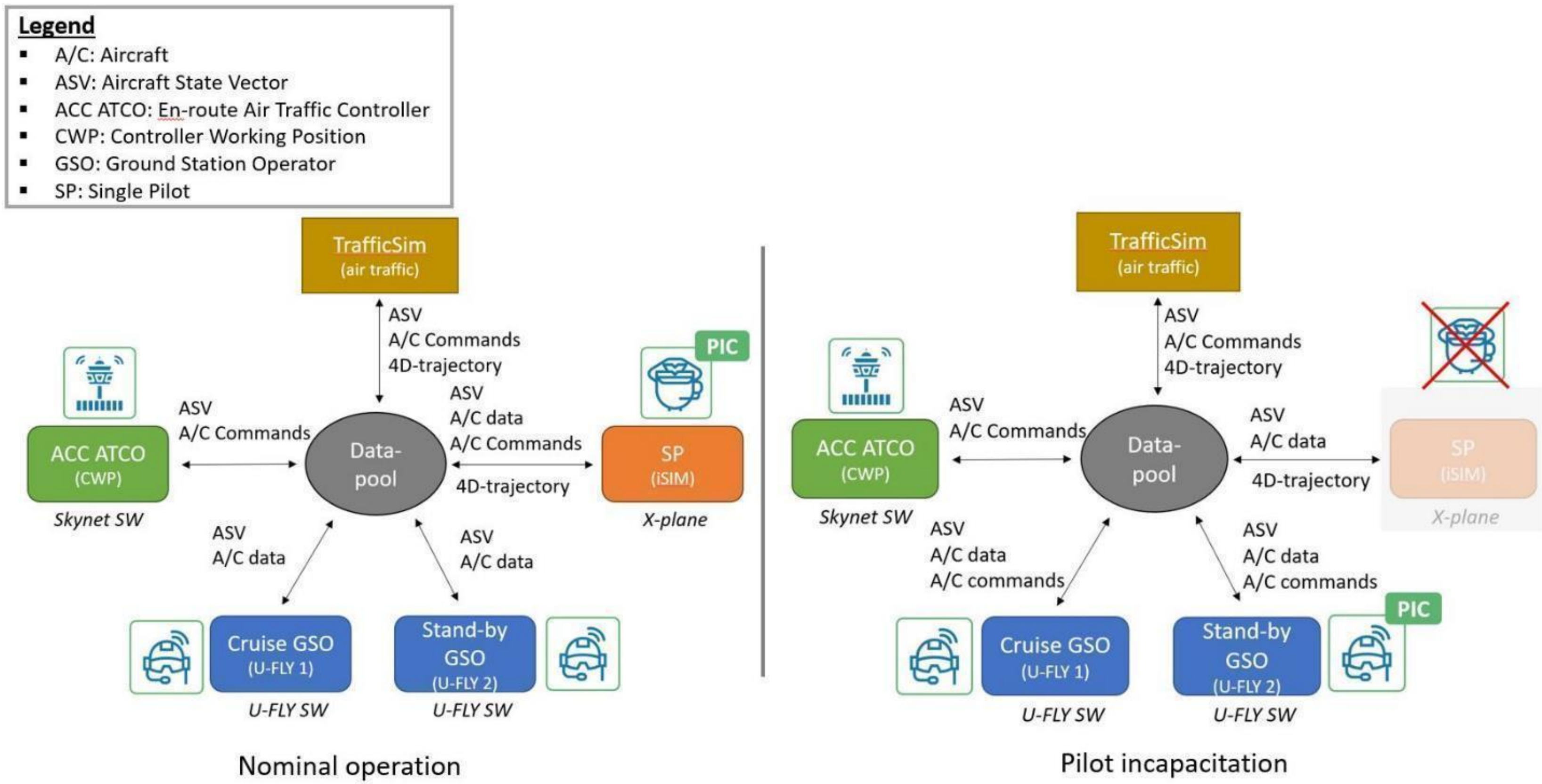

Figure 3. Simulation architecture for S01 (pilot incapacitation during cruise)

3.1.2 S02 – simulation architecture

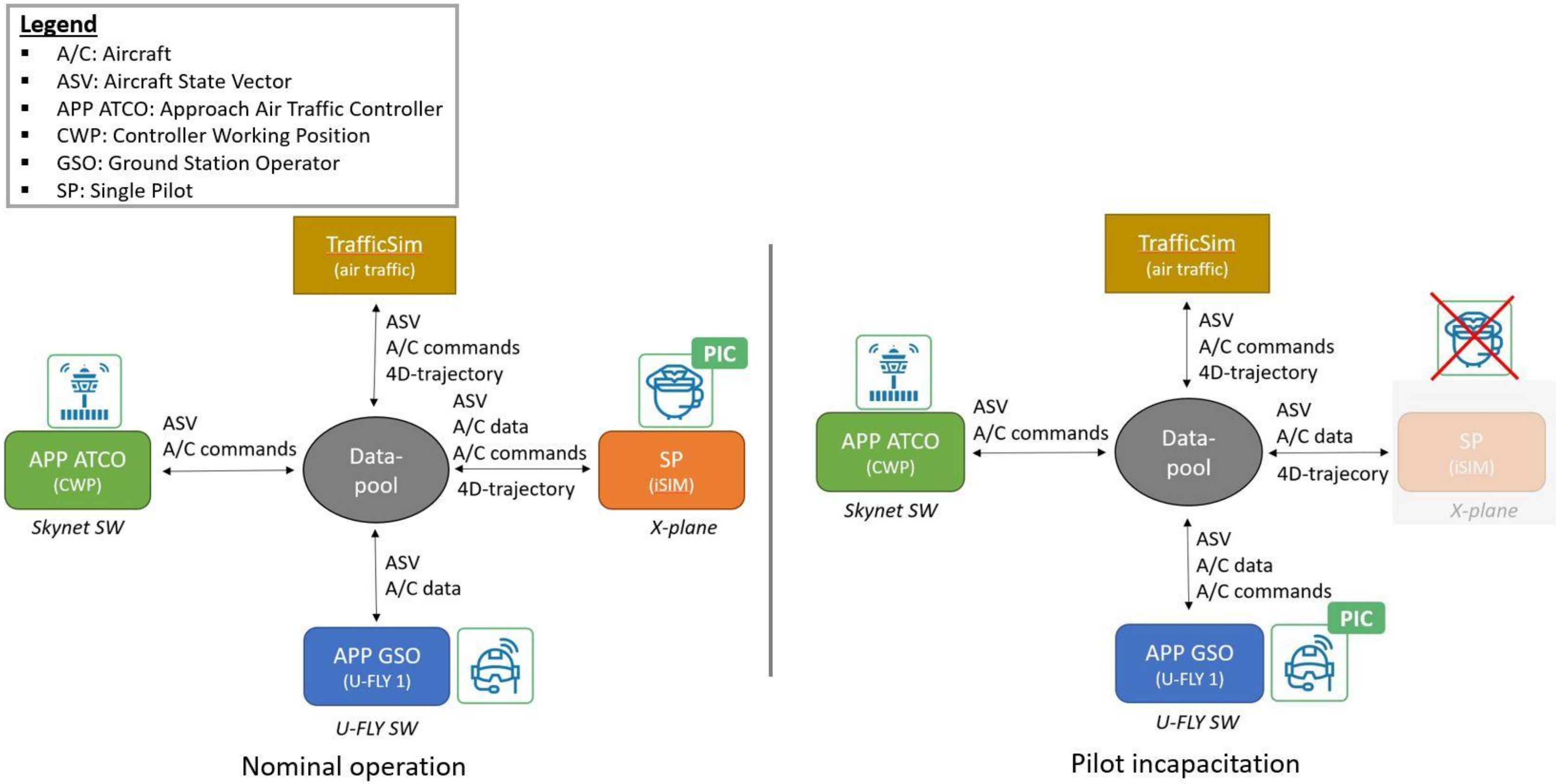

Figure 4. Simulation architecture for S02 (pilot incapacitation in TMA)

3.2 Voice communication infrastructure

An important element of the developed SAFELAND concept of operation is the communication between the human actors involved in the simulated exercises. In order to experience the developed concept in an optimal way, the SAFELAND RTS participants (i.e. ATCO, GSOs, SP) are able to communicate via voice amongst each other, and coordinate the simulated situation. The developed simulation environment uses a *TALK* application based on Voice over IP (VoIP), and enables the human operators to communicate via Push-to-Talk (PTT) switch. For ensuring hands-free operation of the PPT switch each human operator is able to activate the communication line via a pedal.

3.2.1 S01 – Voice communication infrastructure

Figure 5 illustrates the envisaged communication infrastructure for the SAFELAND concept in SPO in the en-route flight phase. It is worth noting, that during the SAFELAND simulation exercises all human operators are able to communicate via VoIP (as mentioned above).

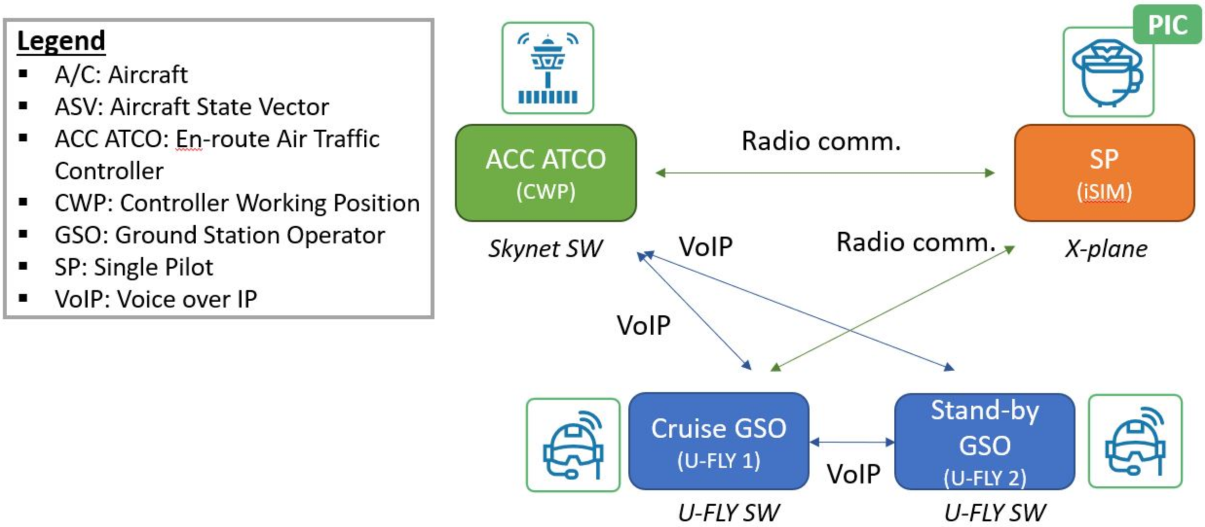

Figure 5. Voice communication infrastructure for the SAFELAND concept during cruise

As in today´s operation, the en-route ATCO and the onboard SP will communicate via radio using defined frequencies for each sector. Moreover, the SAFELAND concept foresees that the GSOs are able to communicate with the SP via radio, as well. Most likely, this will be a separate frequency specifically reserved for the communication between the onboard SP and the GSOs. The actors ATCO, cruise GSO and (if necessary) Stand-by GSO will communicate via landline, preferably VoIP, amongst each other. However, in the SAFELAND concept the cruise GSO and stand-by GSO is not foreseen to get in contact with the en-route ATCO other than in emergency situations (e.g. pilot incapacitation). The GSOs are able to communicate with each other at any time, most probably via VoIP. In theory these two actors could be placed in the same operating room in order to minimise miscommunication, especially crucial in abnormal or emergency situations. However, this depends on the airline specific Standard Operating Procedures or the specifics of the operation room for the GSOs.

3.2.2 S01 – Voice communication infrastructure

Figure 6 depicts the envisaged communication infrastructure for the SAFELAND concept in SPO during departure and approach flight phases. It is worth noting, that during the SAFELAND simulation exercises all human operators are able to communicate via VoIP (as mentioned above).

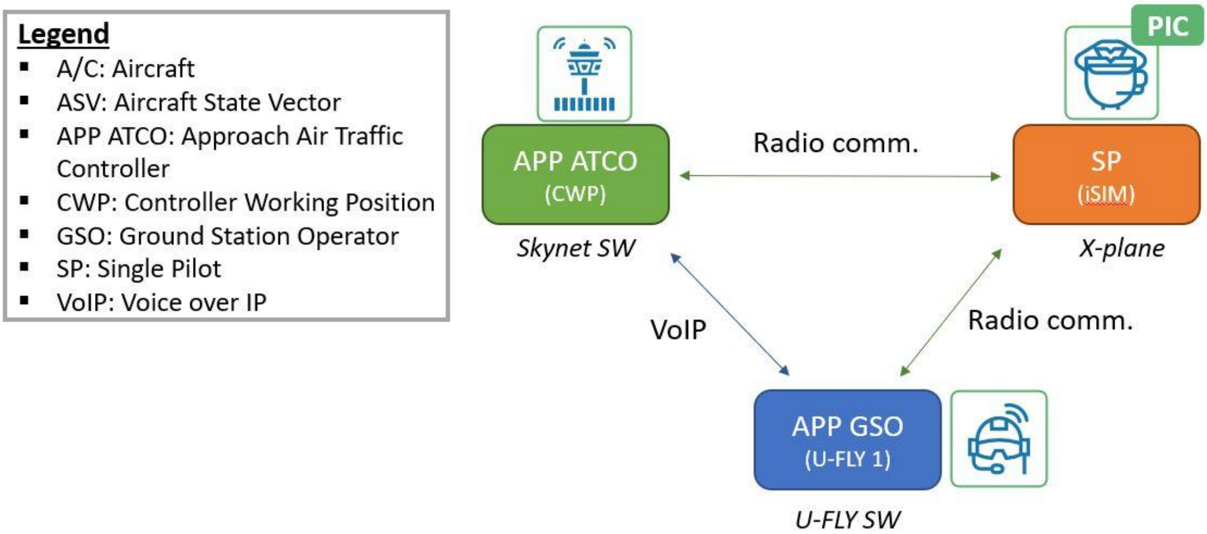

Figure 6. Voice communication infrastructure for the SAFELAND concept in TMA

The approach ATCO and the onboard SP will be able to communicate via radio using defined frequencies for the respective sector. In a similar way, the approach GSO will be able to communicate with the SP via radio. As in the en-route phases, this will probably be a separate frequency specifically reserved for the communication between the onboard SP and the GSOs. The approach ATCO and the approach GSO will communicate via landline, preferably VoIP, amongst each other. However, in the SAFELAND concept approach GSO is not foreseen to get in contact with the approach ATCO other than in emergency situations (e.g. pilot incapacitation).

4 Simulators and software tools

4.1 Data distribution tool *Datapool*

Datapool is the central part of the software environment that will be used in the SAFELAND simulation exercise, as it distributes the data between the different components or simulators. The Datapool tool provides a central communication server as shown in Figure 7. Every connected Datapool client (i.e. the different simulators) has only one interface to the Datapool server.

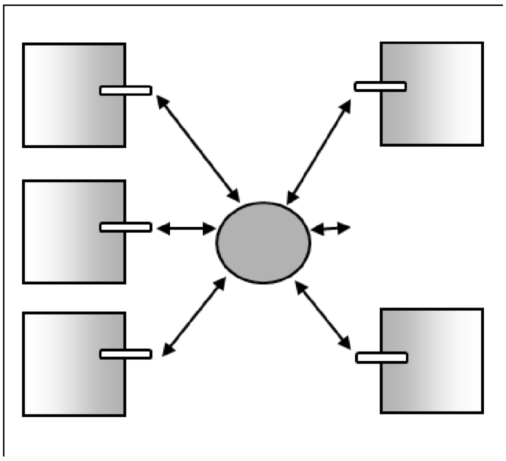

Figure 7. Datapool architecture

Datapool architecture advantages:

- Each client has only one interface
- Standardized interface software (i.e. each client uses the same interface software)
- The communication protocol is black-boxed in the Datapool interface software.
    - Modifications in the communication software do not affect the client software.
- Data transfer is done via messages.
    - The communication protocol is independent of the data structure.
    - Modifications in the data structure do not affect the communication software.

Datapool and its library are both implemented in "C". "C" is a computer programming language supporting structured programming (Kernighan et. al. 1988). The supervisor graphical display uses OpenGL and glut. More features include a recording/replay function.

Data transfer is done via sending and receiving Datapool messages. Each message must start with a message code. The message code can be followed by any number of data bytes. If two clients want to exchange data, they have to agree on a message number and a data format. The sending client just sends the message to the Datapool, where it appears in the list of messages. The receiving client connects to the Datapool, subscribes to the message number and periodically polls the Datapool for new messages. Large messages are stored and transferred compressed. Datapool creates a unique message number and a timestamp for each message code. Message number and timestamp are delivered to the reader clients. For Datapool the data inside the message is not relevant as it only identifies the message by the message number.

By default, Datapool runs with a supervisor display (Figure 8), which shows the list of connected clients, a list of available messages with sender client/timestamp/message number, and the registered reader clients.

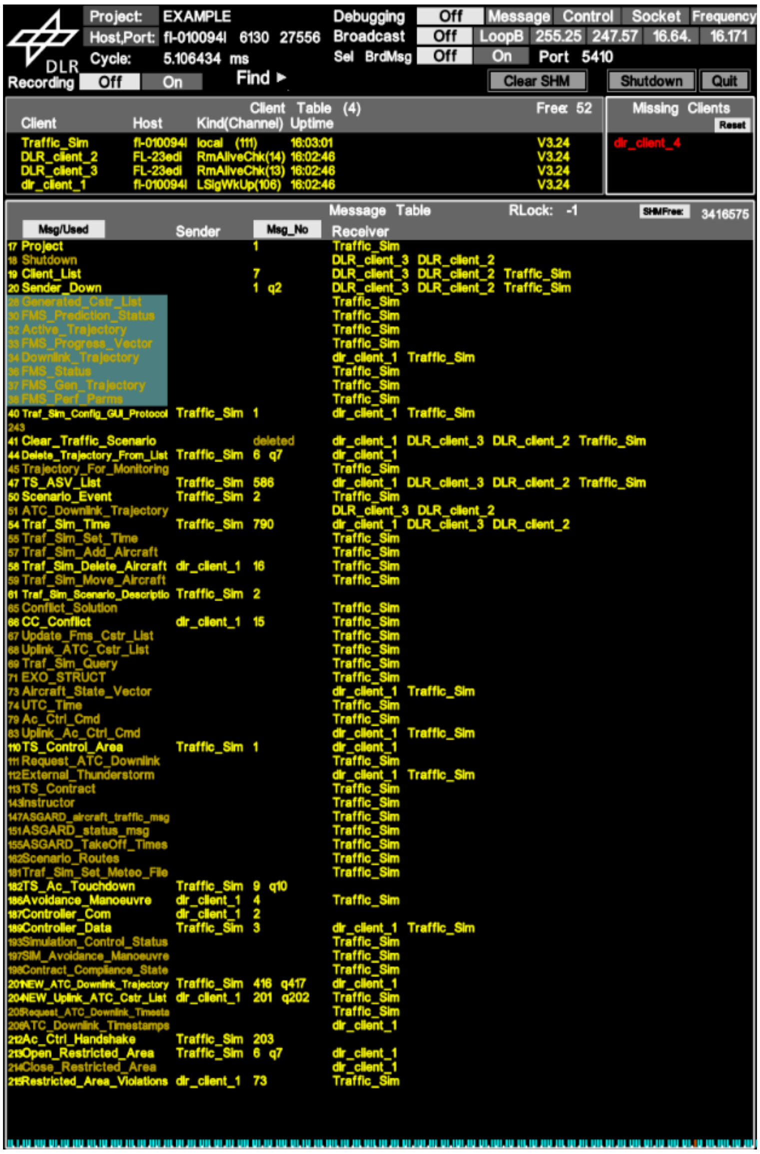

Figure 8. Screen of datapool GUI

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4.2 Air traffic simulation TrafficSim

Within SAFELAND TrafficSim supplies all simulation tools (i.e. Datapool) and simulators (i.e. Remote Pilot Station, CWP) with realistic aircraft data for all aircraft flying in a specific traffic scenario. Hereby, TrafficSim is able to provide a sophisticated air traffic simulation that can simulate large scale traffic scenarios (>10.000 A/C) in real time. The simulator performs motion simulation for thousands of aircraft of mixed equipment (FMS-equipped, FMS-unequipped) flying interactively at the same time. The FMS-equipped aircraft are simulated with an on-board 4D-FMS that follows the predicted trajectory on its own. The FMS-unequipped aircraft follow vectors using the built-in autopilot function.

Scenarios can have any size and complexity - from a realistic day over Europe (or predicted future traffic density, e.g. 200%), or airport-centred arrival and departure scenarios, to small use cases with only few aircraft. In S01 of the SAFELAND RTS, a traffic scenario of a realistic day (i.e. 29.06.2019) over the Hungarian airspace has been chosen to be simulated. In S02 of the SAFELAND RTS, an airport centred arrival scenario of Düsseldorf airport (EDDL) has been chosen to be simulated. Each aircraft is defined by:

- the aircraft type, which can be one of the defined aircraft types in EUROCONTROL´s BADA (Base of Aircraft Data V3.5 or V3.6);
- the flight plan (List of waypoints and constraints in 3D + time);
- TakeOff Time or Aircraft State Vector for the starting position.

The traffic simulator generates a 4D-trajectory for each aircraft participating in the scenario and simulates the aircraft along the trajectory in real time. Figure 9 shows a large traffic scenario over Europe with numerous flights over Germany.

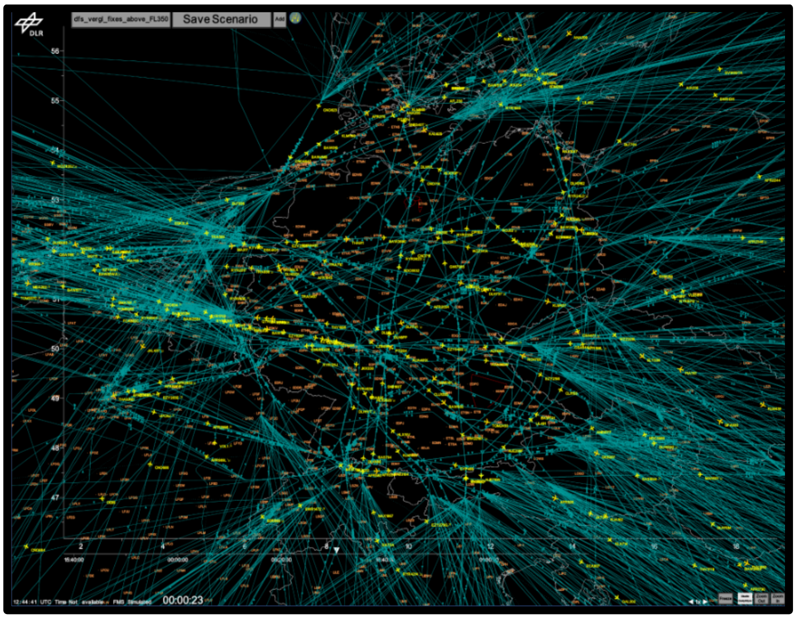


Figure 9. High traffic scenario of Europe provided by TrafficSim

4.3 Cockpit simulator iSIM

In the frame of the SAFELAND RTS, DLR´s fully integrated cockpit simulator *iSIM* will be used as the single pilot cockpit simulator. A detailed description of the simulator and its capabilities has been provided in deliverables D2.2 (SAFELAND, 2022b) and D3.1 (SAFELAND, 2021a).

4.3.1 Input and Output data

This section defines the data types exchanged between the CWP and the SAFELAND simulation architecture. Details on the messages within the data types below, will be given in section XY.

Table 3 depicts the input data of the cockpit simulator iSIM for the SAFELAND RTS.

No	Name	Description	Format
1	A/C commands	High-level aircraft commands (e.g. heading, altitude) sent to the simulated aircraft (i.e. iSIM) incl. FPL changes	ASCII

Table 3. Input data types for the Cockpit simulator (i.e. iSIM)

Table 4 depicts the output data of the cockpit simulator iSIM for the SAFELAND RTS.

No	Name	Description	Format
1	A/C data	Aircraft system and pilot health data sent to the Remote Cockpit simulator (i.e. U-FLY)	ASCII
2	ASV	Aircraft State Vector of the simulated aircraft (i.e. x-plane/iSIM)	ASCII
3	4D trajectory	Trajectory information (incl. FPL) sent to the	ASCII

Table 4. Output data types for the Cockpit simulator (i.e. iSIM)

4.4 Remote Cockpit simulator U-FLY

During the SAFELAND RTS, the remote cockpit simulator U-FLY will be used as the remote piloting station for the GSOs (i.e. cruise GSO, stand-by GSO). A detailed description of the simulator and its capabilities has been provided in deliverables D2.3 (SAFELAND, 2022c) and D3.1 (SAFELAND, 2021).

4.4.1 Input and output data

This section defines the data types exchanged between the Remote Cockpit simulator and the SAFELAND simulation architecture. Details on the messages within the data types below, will be given in section 5.

Table 5 depicts the input data of the Remote Cockpit simulator U-FLY for the SAFELAND RTS.

No	Name	Description	Format
1	ASV	Aircraft State Vector of every simulated aircraft (i.e. simulated by TrafficSim and x-plane/iSIM)	ASCII
2	A/C data	Aircraft system data and pilot health data received from the simulated aircraft in need (i.e. iSIM)	ASCII

Table 5. Input data types of the Remote Cockpit simulator

Table 6 depicts the output data of the ground control station simulator U-FLY for the SAFELAND RTS.

No	Name	Description	Format
1	A/C commands	High-level aircraft commands (e.g. heading, altitude) sent to the simulated aircraft (i.e. iSIM) incl. FPL	ASCII

Table 6. Output data types of the Remote Cockpit simulator

4.5 Controller Working Position

In the SAFELAND RTS, a simulated CWP will be used in order to monitor and manage the surrounding air traffic. A detailed description of the simulator and its capabilities has been provided in deliverables D2.2 (SAFELAND, 2022b) and D3.1 (SAFELAND, 2021).

4.5.1 Input and output data

Table 7 depicts the input data of the controller working position simulator U-FLY for the SAFELAND RTS. Details on the messages within the data types below, will be given in section 5.

No	Name	Description	Format
1	ASV	Aircraft State Vector of every simulated aircraft (i.e. simulated by TrafficSim and x-plane/iSIM)	ASCII

Table 7. Input data types of the CWP simulator

Table 8 depicts the output data of the controller working position for the SAFELAND RTS.

No	Name	Description	Format
1	A/C commands	High-level aircraft commands (e.g. heading, altitude) sent to the simulated surrounding air traffic (i.e. simulated by TrafficSim)	ASCII

Table 8. Output data types of the CWP simulator

5 Data description

As shown in Figure 3 and 4, in total, four different types of data will be transferred between the different simulation tools within the SAFELAND RTS. Each data type consists of different messages that will be transferred. This section illustrates the various messages exchanged within these data types. These data types can be listed as follows:

- Aircraft State Vector (ASV)
- 4D trajectories (planned/re-planned/active) incl. constraint list (flight plan with waypoints and departure/arrival information)
- A/C data (aircraft system data)
- A/C commands (commands send to FMS of aircraft via Remote Cockpit simulator or CWP)

5.1 Aircraft State Vector

Message Name Aircraft State Vector (ASV)

Message Type afcs_aircraft_state_vector_type

Name	Description	Type	Range/ Value	Unit
latitude	Geographic latitude	double	[-π/2, π/2]	rad
longitude	Geographic longitude	double	[-π, π]	rad
altitude	Pressure Altitude	float	[-700,30000]	m
altitude_rate	Vertical speed	float	[-500,500]	m/s
cas	Calibrated Air Speed	float	[0,400]	m/s
ground_speed	Ground Speed	float	[0,800]	m/s
tas	True Air Speed	float	[0,800]	m/s
mach	Mach	float	[0,5.0]	
bank_angle	Bank angle	float	[-π, π]	rad
heading	True Heading	float	[-π, π]	rad
track	Track angle	float	[-π, π]	rad
track_rate	Track angle rate	float		rad/s
pitch	Pitch attitude	float	[-π, π]	rad
thrust	Engine Thrust	float		N
n1_left	Left engine	float		%
n1_right	Right engine	float		%
Zero_Fuel_Weight	Aircrafts empty weight	float		N
Fuel_Weight	Fuel weight at Take Off	float		N

used_fuel_weight	Used Fuel Weight	float		N
fuel_flow	Fuel Flow	float	[0,30]	kg/s
wind_speed	Wind Speed	float	[0, 100]	m/s
wind_angle	Wind direction, wind comes from	float	[-π, π]	rad
air_temperature	Air Temperature	float	[100,450]	K
air_pressure	Air pressure	float	[10000, 1000000]	N/m^2
qnh	QNH	float	[10000, 1000000]	N/m^2
radar_altitude	Radar Altitude	float		m
efcu_alt	Altitude selected via EFCU (Clearance)	float		m
utc_time	UTC time	float		s
flaps	ATTAS : Flaps angle 1 irbus : Flaps Setting 1.0 = Conf 0 0.5 = Conf 1 2.0 = Conf 1+F 3.0 = Conf 2 4.0 = Conf 3 = FULL	float		
sim flaps	Setting of ATTAS Simulation Flaps	float		rad

Message Name Aircraft State Vector flags

Message Type asv_flag_type

Name	Description	Type	Range/ Value	Unit
airborne	Determines whether generation starts from air or from ground	bit	[0,1]	
lateral_guidance_active	Determines whether autopilot follows FMS generated lateral guidance commands	bit	[0,1]	
profile_guidance_active	Determines whether autopilot follows FMS generated vertical guidance commands	bit	[0,1]	

efcu_alt_pushed	EFCU altitude selection button pushed	bit	[0,1]	
spoiler	Spoiler state	bit	[0,1]	
gear_state	Gear State	bit	[0,1]	
ILS_intercepted	Determines whether autopilot has captured ILS already	bit	[0,1]	
ILS_intercept_armed	Determines whether ILS_intercept autopilot function is armed	bit	[0,1]	
goaround_performed	Determines whether aircraft performes goaround	bit	[0,1]	
asep_enabled	Determines whether autopilot is controlled via airborne separation ensurance system	bit	[0,1]	
emergency	Determines whether aircraft is in emergency state	bit	[0,1]	
conflict_detected	Determines whether airborne separation ensurance system has detected a separation violation with another aircraft	bit	[0,1]	

5.2 Constraint list

Message Name Constraint list

Message Type cstr_list_type

Name	Description	Type	Range/ Value	Unit
source	source of constraint list	cstr_list_source_type	pilot, ground, whatif,intend, regen	enum
co_route	name of company route	char[8]	6 Char + \0 + 1WB	
take_off_time	take off time dd:mm:yyyy hh:mm:ss	char[20]	19 Char + \0	
cruise_alt	cruise altitude	float	> Trans_Alt < Max_Cruise_Alt	m
sid	Standard Instrumental Departure: Name and number of SID waypoints	route_segment_type		
star	Standard Arrival Route : Name and number of STAR waypoints	route_segment_type		
departure_airport	definition of departure airport	airport_type		
arrival_airport	definition of arrival airport	airport_type		

descent_spec	specification of descent kind and approach data	descent_spec_type		enum
path_str	description of path stretching area	path_str_type		
cstr_flags	cstr list attributes	cstr_flags_type		
no_waypoints	number of waypoints	int	[0,MAX_WAYPOINTS]	
waypoint	list of waypoint description	cstr_point_type		

Message Name SID, STAR

Message Type route_segment_type

Name	Description	Type	Range/ Value	Unit
name	name of route segment	char[8]	6 Char + \0 + 1WB	
no_waypoints	number of waypoints of this route segment	int	[0,MAX_WAYPOINTS]	

Message Name Arrival airport, departure airport

Message Type airport_type

Name	Description	Type	Range/ Value	Unit
name	airport ICAO identifier	char[8]	4 Char + \0 + 3WB	
runway_name	runway name	char[4]	3 Char + \0	
TMA_na_lmt_alt	Noise Abatement Limit Altitude in Terminal Manoevring Area to specify in departure airport only	float	default: 2000 ft	m
TMA_speed_restr_alt	Speed Restriction Altitude in Terminal Manoevring Area	float	default: FL100	m
transition_alt	transition altitude used for departure airport only	float	default: 5000 ft	m
runway_threshold	runway elevation	float		m
runway_lat	runway latitude	float		rad
runway_long	runway longitude	float		rad

Message Name Descent and approach specification

Message Type descent_spec_type

Name	Description	Type	Range/ Value	Unit
descent_kind	specification of descent profile	Descent_kind_type	Low_Drag_Low_Power, Continous_Descent, Steep_Continuous_Descent	
start_of_steep_descent	start of steep descent altitude for Steep_Continuous_Descent only	float	> Intercept Alt < 8000 ft	m
intercept_alt	intercept altitude, for arrival airport only	float	default: 3000 ft	m
glideslope angle	glideslope angle, for arrival airport only	float	default: 3 degree	rad
level_at_gate	level at gate length	float	default: 5 Nm	m

Message Name Path stretching definition

Message Type path_str_type

Name	Description	Type	Range/ Value	Unit
kind	geometry of path stretching	path_str_kind_type	none,fan,trombone, forced_none, point_merge	enum
entry_point_no	for point_merge only: defines the start of the arc	int		
inner_range	max. allowed distance to move the path stretching intercept waypoint in airport direction	float		m
outer_range	max. allowed distance to move the path stretching intercept waypoint opposite to airport direction	float		m

Message Name Constraint list flags

Message Type cstr_list_flags_type

Name	Description	Type	Range/ Value	Unit
passed_waypoint_included	determines whether the first waypoint is already behind current aircraft position. The over flown waypoint is included in the cstr_list to keep an altitude constraint or CAS constraint description of passed waypoint	bit	[0,1]	
insert_metering_fix_level	= 1 ⍰ insert a Metering Fix level constraint when no altitude constraints are defined in STAR	bit	[0,1]	
curved_approach	= 1 ⍰ accept that FAF is specified in turn to intercept leg	bit	[0,1]	
geoidal_approach	= 1 ⍰calculate FAF with constant flightpath angle, without considering deviation from ILS and shape of earth	bit	[0,1]	

Message Name Constraint list waypoint list

Message Type cstr_point_type

Name	Description	Type	Range/ Value	Unit
name	waypoint name	char[8]	5 Char + \0 + 2 WB	
latitude	latitude of waypoint	float	[-π/2, π/2]	rad
longitude	longitude of waypoint	float	[-π, π]	rad
turn_kind	kind of turn	turn_kind_type	no_turn, mid_of_turn, start_of_turn_clockwise start_of_turn_anticlockwise, start_of_turn_as_appropriate	enum
turn_radius	turn radius	float	Enroute: [3,15Nm] Default 6 TMA: [1,15Nm] Default 3.5	m
alt_cstr_kind	kind of altitude constraint Local: A local constraint defines an altitude window at the waypoint where theconstraint is specified. The trajectory must pass through the defined	alt_cstr_kind_type	no_cstr local level	enum

Founding Members

	altitude window and the trajectory is unconstrained before and after the constraint point. **Level:** A level constraint defines a restrictedarea. The restricted area starts at the waypoint where the level constraintis specified and ends at the next waypoint.			
upper_alt	upper altitude constraint	float		m
lower_alt	lower altitude constraint	float		m
cas_cstr_exists	=1 CAS constraint is specified	int	[0,1]	
min_cas	min. allowed speed	float	[0,400]	m/s
max_cas	max. allowed speed	float	[0,400]	m/s
time_cstr_exists	=1 Time constraint is specified	int	[0,1]	
time_cstr_exists	=1 Time constraint is specified	int	[0,1]	
early_time	early time constraint, aircraft should be after early_time at waypoint	char[12]	8 Char + \0 + 3 WB	
late_time	late time constraint, aircraft should be befor late_time at waypoint	char[12]	8 Char + \0 + 3 WB	
holding_exists	=1 This waypoint is a possible holding waypoint	int	[0,1]	
max_holding_distance	maximum length of a straight segment in a holding circuit	float		m

5.3 4D trajectory

Message Name ts_trajectory_type

Name	Description	Type	Range/ Value	Unit
ac_code	BADA aircraft type	char[8]		

no_climbs	Number of climb segments in trajectory	int		
no_descents	Number of descent segments in trajectory	int		
climb	list of climb segments	subphase_index_type[]		
descent	list of climb segments	subphase_index_type[]		
no_points	number of trajectory points	int		
point	vector of trajectory points	std::vector<fms_gen_trajectory_point_type >		

Message Name subphase_index_type

Name	Description	Type	Range/ Value	Unit
start	index of point where segment begins	short int		
end	index of point where segment ends	short int		

Message Name fms_gen_trajectory_point_type

Name	Description	Type	Range/ Value	Unit
cstr_no	number of last waypoint passed	int		
segment_no	number of current segment	int		
segment_kind	kind of current segment	segment_kind_type (enum)	0 = Unknown_Segment_Kind 1 = Straight_Segment 2 = Start_Of_Turn_Segment 3 = First_Half_Of_Turn_Segment 4 = Second_Half_Of_Turn_Segment	
subphase_no	number of current subphase	int		
time	current time	char[10]	hh:mm:ss	
rel_time	current time (in seconds)	float		s
distance_along_route	total distance travelled above ground	float		m
latitude	Trajevtory point latitude	float	[-π/2, π/2]	rad
longitude	Trajectory point longitude	float	[-π, π]	rad
altitude	altitude above ground	float		m
altitude_rate	vertical speed	float		m/s
cas	Calibrated air speed	float		m/s
cas_rate	CAS rate	float		m/s²
ground_speed	speed above ground	float		m/s
tas	True air speed	float		m/s
mach	Mach number	float		

track	track angle	float	[-π, π]	rad
track_rate	track angle rate	float		rad/s
thrust	Engine thrust	float		N
ac_weight	current aircraft weight	float		N
fuel_flow	fuel flow	float		kg/s
ac_config	flaps and gear setting, combinations of flaps angles and gear state	aircraft_config_type (enum)	0 = Flaps_In_Gear_Up 1 = Flaps_1_Deg_Gear_Up 2 = Flaps_5_Deg_Gear_Up 3 = Flaps_14_Deg_Gear_Up 4 = Flaps_35_Deg_Gear_Up 5 = Flaps_In_Gear_Down 6 = Flaps_1_Deg_Gear_Down 7 = Flaps_5_Deg_Gear_Down 8 = Flaps_14_Deg_Gear_Down 9 = Flaps_35_Deg_Gear_Down	
flaps	angle of flaps	float		rad
config_flags	gear and spoiler state	config_flags_type		
wind_speed	wind speed	float		m/s
wind_direction	wind direction ("coming from")	float	[-π, π]	rad
air_temperature	airt temperature	float		K

Message Name config_flags_type

Name	Description	Type	Range/ Value	Unit
gear_state	state of gear	unsigned int:1	0 = false = up 1 = true = down	
spoiler	state of spoilers	unsigned int:1	0 = false = unset 1 = true = set	
free	Unused	unsigned int:30		

5.4 A/C data

Message Name Aircraft System data

Category	Name	Description	Type	Range/ Value	Unit
F/ CTL	SPD BRK 1	Position of left speed brake	int	[0,1]	
	SPD BRK 2	Position of right speed brake	int	[0,1]	
	Aileron L	Position of left aileron	int		
	Aileron R	Position of right aileron	int		
	ELEV L	Position of left elevator	int		

	ELEV R	Position of right elevator	int		
	ELAC		int		
	SEC		int		
	TRIM		int		
	RUD		int		
Wheel	Wheel position front	Position of front wheel	bit	[0,1]	
	Wheel positions 1	Position of left wheel	bit	[0,1]	
	Wheel position 2	Position of right wheel	bit	[0,1]	
	Wheel pressure 1	Pressure in left wheel	float	[0, 1000]	psi
	Wheel pressure 2	Pressure in right wheel	float	[0, 1000]	psi
APU	APU N	Auxiliary Power Unit Performance	float	[0, 100]	%
	APU EGT	Auxiliary Power Unit Exhaust Gas Temperature	float	[0, 1000]	C
Fuel	Fuel Used 1+2	Fuel used of left and right main wing tank	float	[0, 100.000]	kg
	Fuel Used 1	Fuel used of left main wing tank	float	[0, 100.000]	kg
	Fuel Used 2	Fuel used of right main wing tank	float	[0, 100.000]	kg
	Fuel Center Tank	Fuel used of center tank	float	[0, 100.000]	kg
	Fuel Inner Tank 1	Fuel used of left inner tank	float	[0, 100.000]	kg
	Fuel Inner Tank 2	Fuel used of right inner tank	float	[0, 100.000]	kg
	Fuel Outer Tank 1	Fuel used of left outer tank	float	[0, 100.000]	kg
	Fuel Outer Tank 2	Fuel used of right outer tank	float	[0, 100.000]	kg
HYD	HYD pressure Green	Hydraulic pressure of left (green) hydraulic system	float	[0, 10.000]	psi
	HYD pressure Blue	Hydraulic pressure of middle (blue) hydraulic system	float	[0, 10.000]	psi
	HYD pressure Yellow	Hydraulic pressure of right (yellow) hydraulic system	float	[0, 10.000]	psi
ELEC	Batterie 1 Voltage	Left battery voltage	float	[0,100]	V
	Batterie 1 Amperage	Left battery amperage	float	[0, 100]	A
	Batterie 2 Voltage	Right battery voltage	float	[0,100]	V
	Batterie 2 Amperage	Right battery amperage	float	[0,100]	A

Engine	Fuel Used	Used aircraft fuel	float		kg
	Oil Quantity	Quantity of engine oil	float		%
	Oil pressure	Pressure of engine oil	float		psi
	Oil temperature	Temperature of engine oil	float		C

5.5 A/C commands

Message Name Aircraft commands

Name	Description	Type	Range/ Value	Unit
Altitude	Pressure Altitude	float	[-700,30000]	m
CAS	Calibrated Air Speed	float	[0,400]	m/s
Heading	True Heading	float	[-π, π]	rad
VS	Vertical Speed	float	[0,400]	m/s
Direct to	Direct to certain [waypoint]	bit	[0, 1]	

6 Data Recording

In addition to the various data gathering methods stemming from the objective to collect information from the RTS participants for the human factors' considerations (e.g. questionnaires, debriefings, discussion groups), the used simulation environment will be able to record simulation data (e.g. ASV, 4D trajectory, etc.) during the SAFELAND scenarios. The subsections below describe the data recording capabilities of the simulation environment. Consent forms per participant will be collected prior to the simulation exercises.

6.1 Simulator data recordings

As described in section 4.1, the Datapool application is the central part of the simulation infrastructure and has the capability to record the received and transmitted simulation data. Hereby, Datapool is able to record all message coming from, and sent, to the different simulators (i.e. Cockpit simulator, Remote Cockpit simulator, CWP) involved in the SAFELAND use-cases. Especially the following data types including their messages will be recorded:

- Aircraft State Vector (ASV)
- 4D trajectories (planned/re-planned/active) incl. constraint list
- A/C commands (commands send to FMS of aircraft via Remote Cockpit simulator or CWP)

As a result of these data recording capabilities, each RTS session can be post-processed by replaying the recorded scenarios in which the RTS participants reacted to the simulated situation. Hence, the different strategies to implement and realise the SAFELAND concept of operations per participant can be analysed afterwards.

6.2 Screen and video recordings

Screen recordings of the Remote Cockpit simulator (as depicted in D2.3) and the CWP (as depicted in D2.1) will be gathered for each scenario and participant individually. By using the *OBS Studio* software tool, the entire operator screen will be recorded including mouse movements. Hence, a detailed analysis of the performed operational steps from each participant can be conducted afterwards. Furthermore, video recordings of all three operator rooms depicting the human operators managing the situation will support the RTS analysis to be conducted in WP3.

6.3 Voice communication recordings

Voice communication between the human operators will be realised via a PPT application. Via the *OBS Studio* software tool all communications between the human operators will be recorded for each of the RTS sessions. Consequently, a detailed analysis of the communication processes and procedures can be performed afterwards.

7 Integration Testing

Testing and validating the overall SAFELAND simulation environment prior to actual RTS is a crucial element of the preparation of the used simulator to the SAFELAND use-cases. These integration tests were performed with DLR simulation experts, HF experts and DLRs project management colleagues in order to ensure the proper implementation of the soft- and hardware specific changes made on each simulator individually. However, due to the concerning COVID-19 situation in winter 2021/2022 (November 2021 - February 2022), especially in Germany, the integration test sessions were conducted with a limited number of personnel following strict COVID-19 protocols (e.g. fully vaccinated, social distancing, separate lunch breaks, etc.). As a consequence of the COVID situation, the individual simulator adaptation and programming of interfaces for each simulator was done prior to these test sessions via remote access mainly from HomeOffice by DLR simulation experts. As a result, the aim of the performed integration test sessions was to verify the overall simulation environment adapted to the SAFELAND use-cases and validating the interface adaptations made to the individual simulators. In the end, a complete Dry-Run session (i.e. test session 3) running the planned SAFELAND scenarios for the RTS has been performed and achieved successfully.

In total, three integration test sessions in the laboratories of DLRs Institute of Flight Guidance were conducted from mid-November 2021 to end-January 2022. The subsections below will detail the general objective including the performed actions of each test session. Furthermore, they will illustrate the planned schedule and summarise the outcome per test session.

7.1 Test session 1

The first integration test session was held from 23th - 25th November 2021. The main objective of this test session was to bring the software application of each simulator up-to-date for the SAFELAND purposes. As mentioned above, prior to this test session the software applications for each simulator were adapted to the SAFELAND use-cases via remote access from HomeOffice. However, in order to transfer these software changes to the simulators located in the Institute, software updates had to be downloaded and installed for each simulator individually. In addition, testing and verification of each simulator's interfaces was performed as well. Hereby a recorded traffic scenario was re-played in order to verify and validate the data exchanges between the connected simulators (i.e. Datapool, TrafficSim, Remote Cockpit simulator (U-FLY), Cockpit simulator (iSIM), CWP (Skynet tool)).

7.1.1 Performed actions and schedule

Table 9 lists the performed actions described in more detail above and depicts the required time slots. It is worth noting that other commitments (also outside of the SAFELAND project) had to be fulfilled within these time slots. Consequently, the listed actions did not necessarily last the entire time slot mentioned below.

	Tuesday	Wednesday	Thursday

Morning	Software update of Remote Cockpit simulator	Software update of CWP	Update of required plugin for x-plane 11 on Cockpit simulator
Afternoon	Interface and data exchange verification of Remote Cockpit simulator	Interface and data exchange verification of CWP	Interface and data exchange verification of Cockpit simulator

Table 9. Schedule and action items for first integrated test session

7.1.2 Outcome

In general, the software updates per simulator and interface verification was successful. Minor bug fixing and interface corrections were performed during this test, but the general objective to update the simulators was performed successfully.

7.2 Test session 2

The second integration test session was held from 17th - 19th January 2022. The main objective of this test session was to establish the communication infrastructure required for the SAFELAND RTS and afterwards verify the implemented communication network. As (voice) communication between involved actors (and thereby between the different simulators) is a crucial element of the proposed SAFELAND concept, it was agreed (DLR internally) to use the *TALK* application which is already a well-established application for simulation purposes within DLR. Hereby all human actors can intercommunicate via VoIP. Via PPT, the communication line will be activated for each actor (e.g. ATCO, GSO, SP) individually. At first, the TALK application had to be set up and updated on each simulator. Hereafter the correct settings were implemented and verified. In the end, several verification tests were conducted with communication between all simulators. Table 10 lists the performed actions as well. In addition, minor final HMI design adaptations, especially on the Remote Cockpit simulator (U-FLY), were discussed and implemented before the final test session (i.e. Test session 3).

7.2.1 Performed action and schedule

Table 10 lists the performed actions of the 2nd test session which are described in more detail above. It is worth noting that other commitments (also outside of SAFELAND) had to be fulfilled within these time slots as well. Consequently, the listed actions did not necessarily last the entire time slot mentioned below.

	Monday	Tuesday	Wednesday
Morning	Setup and updating TALK application on Remote Cockpit simulator	Implementation of PPT functionality via a newly developed pedal for each simulator	Testing and verification of TALK application and PPT functionality on all three simulators (1st round)

Afternoon	Setup and updating TALK application on CWP and Cockpit simulator	Initial testing of PPT functionality via pedal; Final HMI design adaptation on Remote Cockpit simulator	Testing and verification of TALK application and PPT functionality on all three simulators (2nd round)

Table 10. Schedule and action items for the second test session

7.2.2 Outcome

The (voice) communication infrastructure as required for the SAFELAND RTS was implemented and verified successfully. As a result, the human operators of the SAFELAND RTS are able to intercommunicate (as required) via a PPT application (i.e. TALK app) during the simulation exercises to be held early May 2022.

7.3 Test Session 3

The third integration test session was held from 24th - 28th January 2022. The main objective of this test session was to test and verify the entire SAFELAND simulation environment required for the RTS planned in May, 2022. Hereby multiple “Dry Run” sessions simulating both SAFELAND scenarios (i.e. S01: pilot incapacitation in en-route, S02: pilot incapacitation in TMA) with DLR employees acting as ATCO, GSOs and SP were conducted. On Monday and Tuesday minor software and final testing of simulation infrastructure was performed as preparation of the planned Dry Run sessions for the next days. On Wednesday to Friday the performed Dry Run sessions verified the entire simulation infrastructure as required for the RTS whilst conducting the SAFELAND specific scenarios. These sessions included video and screen recordings of the simulators. The results of these video recordings can be found in the deliverables D2.1, D2.2 and D2.3.

7.3.1 Performed actions and schedule

Table 11 lists the performed actions described in more detail above and depicts the required time slots.

	Monday	Tuesday	Wednesday
Morning	Final software update on all three simulators	Final tests and verification of (voice) communication infrastructure	Dry Run session - Video recording S01 (en-route) incl. multiple video takes
Afternoon	Testing and verification of data exchange after the software updates	Initial preparation for “Dry Run” sessions and video recording for the next days	Dry Run session- Video recording S01 (en-route) incl. multiple video takes

	Thursday	Friday

Morning	Dry Run session - Video recording S02 (approach) incl. multiple video takes	Dry Run session - Video recording S02 (approach) incl. multiple takes
Afternoon	Dry Run session - Video recording S02 (approach) incl. multiple video takes	Initial video editing on all recorded videos

Table 11. Schedule and action items for third test session ("Dry Run" session)

7.3.2 Outcome

The "Dry Run" sessions were performed successfully. Final software updates of the simulator and minor software debugging was executed during these sessions. As a result, the developed SAFELAND simulation infrastructure consisting of Cockpit simulator (i.e. iSIM), Remote Cockpit simulator (i.e. U-FLY) and CWP (i.e. Skynet tool) has been successfully prepared for the SAFELAND RTS to be held in May, 2022.

8 Part 2 - Low-Fidelity Simulation - Introduction

8.1 Purpose and scope of this document

Part 2 of this document contains the description and results of the SAFELAND Low-Fidelity Simulation (LFS) exercises held online between November and December 2021.

The LFS aimed to provide a first understanding and evaluation of different aspects of the feasibility and validity of the core ideas regarding the incapacitation during landing of a Single Pilot operated aircraft with the support of a Ground Station. The focus of the LFS was on the Ground Station Operator (GSO). Low-fidelity simulations are simpler and less costly than Real-Time Simulations, but already create an understanding of underlying issues regarding roles, procedures, and human-automation interaction. As such, this LFS aims at reducing the risk of the RTS planned for May 2022, providing feedback on the concept, but also on the execution of a simulation itself, uncovering deviations from expectations and thus, allowing the creation of mitigation measures.

The SAFELAND LFS was developed in collaboration with the H2020 SAFEMODE project, which is focused on developing methods and tools for Human Factors informed Design (http://safemodeproject.eu). SAFEMODE provided the templates for console, baseline scripts and initial concept for the simulation scenarios. SAFEMODE also provided the methodology, inquiry, and debriefing structure, derived from the Human Performance Assessment Process (HPAP). SAFEMODE benefited from the participants assessment of the adequacy of the materials and Low Fidelity Simulation approach to support the SAFELAND work.

In SAFELAND, the scenarios and questionnaires were further detailed and fine-tuned to the SAFELAND concept. SAFELAND executed the simulations, collected the data, and analysed it. SAFELAND provided feedback to SAFEMODE on the LFS and HPAP adequacy to support a design process.

8.2 Structure of the document

The document is structured as follows.

- Chapter 8 introduces Part 2.
- Chapter 9 describes methods and materials used in the LFS.
- Chapter 10 provides a summary of the LFS results.
- Chapter 11 provides conclusions and next steps.
- Appendix A contains the LFS questionnaires and debriefing data.

8.3 List of acronyms

Term	Definition
ATCO	Air Traffic Controller
GDPR	General Data Protection Regulation
GSO	Ground Station Operator
GSP	Ground Station Pilot
HPAP	Human Performance Assessment Process
LFS	Low-Fidelity Simulation
OBP	On-Board pilot
RTS	Real-Time Simulation
SA	Situational Awareness
SME	Subject-Matter Expert
SPO	Single Pilot Operation
TMA	Terminal Manoeuvring Area

Table 12: Part 2 Acronyms

9 Method and materials

The LFS were realised in a virtual setting, using an online meeting tool (MS Teams).

In each session, the test subject, a multi-engine commercial licence holder pilot, played the role of GSO[2], while researchers from the SAFELAND consortium played the other roles envisioned by the operational concept and by the LFS tool (see section 9.4.1 Roles) or participated as observers.

Three different runs of flight descent and landing scenarios were performed (see section 9.4.2 Scenarios and script).

After each session, participants answered an anonymous questionnaire, followed by a semi-structured debriefing interview. All sessions were video recorded. After all sessions, both questionnaire results and annotations were collected and analysed.

9.1 Participants

Seven commercial pilots (see details in Table 13) were recruited for the Low-Fidelity Simulation as test subjects. All the participants signed a consent form before the activity, agreeing to be recorded (voice and video). They were reminded that they could withdraw from the simulation activities at any time, and that the data collected would be anonymised.

Session N	Date	GSO Participant	Position/Expertise
1	22/11/2021	Subj 1	Researcher with airline transport pilot licence
2	23/11/2021	Subj 2	Airline pilot - Ryanair, Instructor
3	24/11/2021	Subj 3	Airline pilot - Ryanair, Instructor
4	29/11/2021	Subj 4	Researcher with airline transport pilot licence
5	2/12/2021	Subj 5	Airline Pilot - Lufthansa, HF researcher
6	3/12/2021	Subj 6	Airline Pilot - SWISS, researcher
7	6/12/2021	Subj 7	Airline Pilot - TAP, Flight School Instructor

Table 13. Participants' expertise

[2] Hereafter, for the Approach & Landing role, the two terms Ground Station Operator (GSO) and Ground Station Pilot (GSP) are used interchangeably.

9.2 LFS Approach

The development of the SAFELAND LFS (from conception to execution) can be described by the following steps:

1. **Key research questions identification.** With partners, the key research questions to explore with the Low Fidelity Simulation (LFS) were defined. These were driven by the high-level validation objectives of the SAFELAND project, and key issues regarding the set-up and realisation of the Real Time Simulation (RTS).
2. **Experiments definition.** A baseline flight scenario was defined - landing at Budapest Airport, nominal SPO operation - and from this, two new scenarios were derived, allowing exploration of the research questions (incapacitation during descent keeping previous landing plan, incapacitation during descent under vectoring instructions).
3. **Experimental set-up development.**
    a. Scripts were developed for each scenario, detailing the events and communication lines for each actor. Each script also had a dedicated support console slidedeck (powerpoint). Each slide showed the aircraft situation, as would be perceived by the GSO in a conceptual console. Interaction modes with the console were defined (audio commands, see section 9.4.3 for more details about these commands).
    b. Actors' roles were distributed among partners, according to their expertise domain and availability.
    c. Definition of actions upon script deviations were defined between the partners to prepare for their eventuality during the LFS.
    d. An agenda for the session was developed, taking into account limitations imposed by the LFS context and time. In order to address the issues of time limitations and unfamiliarity with the LFS setting, a briefing pack was created and distributed to the participants. It included descriptions of: operational concept; GSP roles and responsibilities; key procedures; console and systems; and mission information. A companion video was included, showing an example of how the LFS would be experienced for a nominal descent under SPO.
4. **Experimental execution.** Participants were contacted and filled a GDPR acceptance form. Simulation sessions were executed according to a pre-arranged calendar. All scripted actors had access to the scripted spreadsheet. The GSO test subject (our participants) only had access to the briefing pack.
5. **Data analysis** Data and information from questionnaires and debriefing sessions were processed and analysed.

9.3 Research objectives

The main goal of the LFS was to carry out a preliminary evaluation of the SAFELAND concept, focusing on its operational feasibility, and on human performance and safety aspects, from the GSO perspective.

To this aim, starting from the high-level validation objectives of the SAFELAND project, key areas of investigation have been identified and translated into specific validation objectives, as shown in Table 14 below.

High-level VO and Criteria	Investigated areas	Detailed validation objectives: To assess that…
Operational: The concept is considered feasible from the operational point of view	Operational feasibility Operating procedures	*Operational concept is feasible* *Procedures are clear and acceptable*
HP: The concept enables proper human performance levels, and is considered acceptable by the involved actors	Roles, responsibility, and task allocation HMI Situational Awareness Workload Team and communication	*Roles are clear and acceptable.* *Task allocation is effective and efficient* *The HMI supports human actors in their tasks* *Level of Situational Awareness is adequate.* *Level of Workload is adequate.* *Coordination and communication are adequate.*
Safety: The concept contributes to SPO safety compared with operations currently conducted with two pilots	Safety aspects	*Possible other hazards are identified.* *Possible mitigation solutions are proposed*

Table 14. High-level validation objectives, areas of investigation and detailed validation objectives

Moreover, the scenarios, scripts and console developed for the LFS will serve as a framework for the refinement of the RTS environment and RTS execution.

9.4 Experimental set-up

9.4.1 Roles

To execute the simulation, different roles were defined. A description is presented in Table 15, grouping these roles within their simulation domain context.

Role type	Role ID	Description of role	Provided by
LFS Conduction	Game Master	Responsible for setting the cadence of the simulation by changing the slides, simulating console audio feedback upon GSP requests and managing unforeseen GSP actions.	A design team engineer internal to the SAFELAND Consortium.
Scripted Simulation Actors	On-board Pilot (OBP)	Representing the on-board single pilot.	An experienced airline pilot internal to the SAFELAND Consortium.
	Air Traffic Controller	One ATCO representing the different ATCOs which would interact during the flight (cruise, approach, tower).	An experienced ATCO internal to the SAFELAND Consortium.
	Cruise Ground Station Operator	Representing the cruise segment GSO.	A design team engineer internal to the SAFELAND Consortium.
Unscripted Simulation Actor	**Ground Station Operator (GSO)** also referred to as Ground Station Pilot (GSP)	**Reacts to the environment cues presented aurally and within the console.**	**Test subject.** An experienced airline pilot external to the SAFELAND Consortium.
Observation and Registration	Human Factors, Safety and ATM experts	Observing the execution of the simulation, taking notes, and intervening during the debriefing session.	SMEs internal to the SAFELAND Consortium.
	Debriefing Moderator	Leads the semi-structured debriefing session.	SME internal to the SAFELAND Consortium.

Table 15. Roles involved in the LFS

9.4.2 Scenarios and Scripts

The simulation scenario mission is to land at Budapest Airport within the framework of a commercial Single Pilot Operation (SPO). An illustrative flight is shown in Fig. 10 and the flight charts are shown in Fig. 11, focusing on the STAR procedure KEZAL, selected for the simulation.

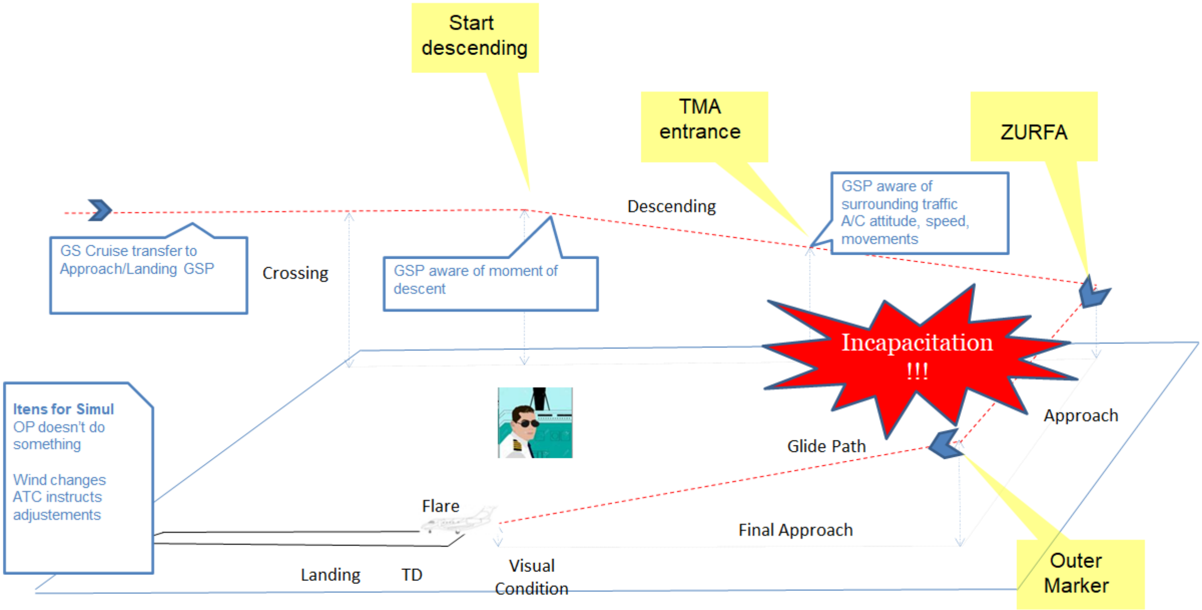


Figure 10. Symbolic representation of scenario flight.

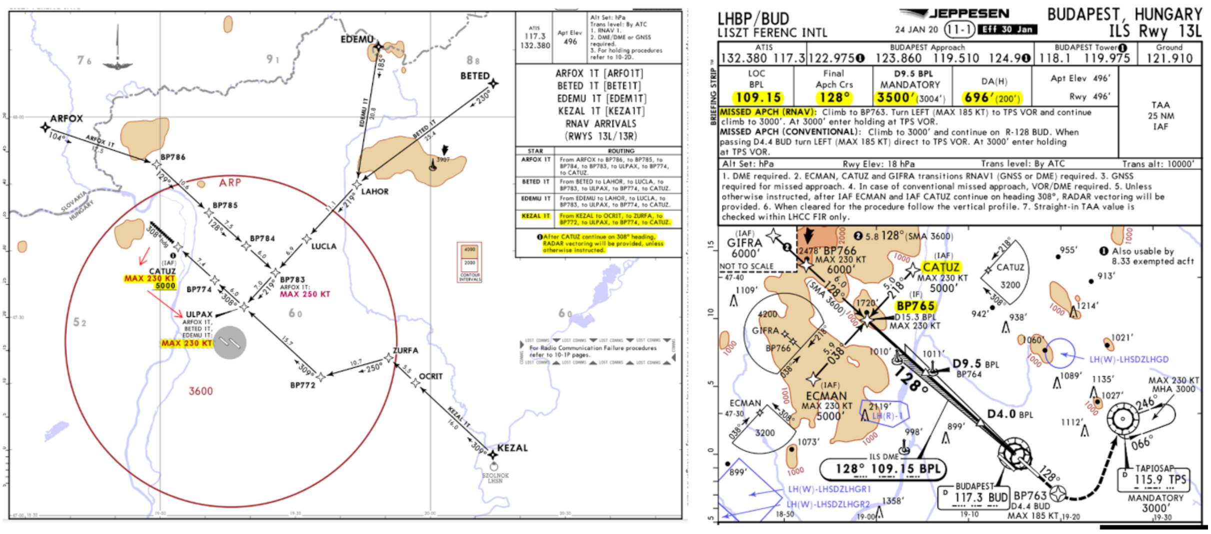


Figure 11: Flight charts (from Jeppesen) into Budapest Airport, with selected STAR procedure for the simulation (KEZAL).

The simulation session required the development of three scenarios:

- **Case 1: Nominal SPO descent and landing.** This scenario was used to familiarise (train) the GSO with the console, nominal procedures, and flight under SPO.
- **Case 2: Incapacitation event within the TMA.** The main research questions for this scenario regarded the ability of the GSO to react to the incapacitation event, assume responsibility for the aircraft and for the ATC communication dynamic.

- **Case 3: Incapacitation under ATC vectoring**. This scenario introduced a slightly more complex situation, one with a potential greater impact on workload and situational awareness. The main research questions for this scenario regarded the ability of the GSP to keep situational awareness and manage the associated workload.

To develop the scenarios, a first baseline script was created using a two-person crew as reference. This was then modified into a nominal SPO crew, incorporating procedures, actors, and systems capabilities of the Single Pilot Operation concept. The nominal SPO script was then further modified to incorporate the incapacitation event, adjusting the calls and actions of the different actors involved. To ensure robustness and adherence of the scripts to both the concept and operations (namely ATC), SMEs took part in the script creation process.

The scripts were developed using spreadsheets (see Fig. 12 script.1), with templates developed within the SAFEMODE project. Each script had a standard header description, detailing identification, general description, key scenario directives, general and specific key assumptions, among others.

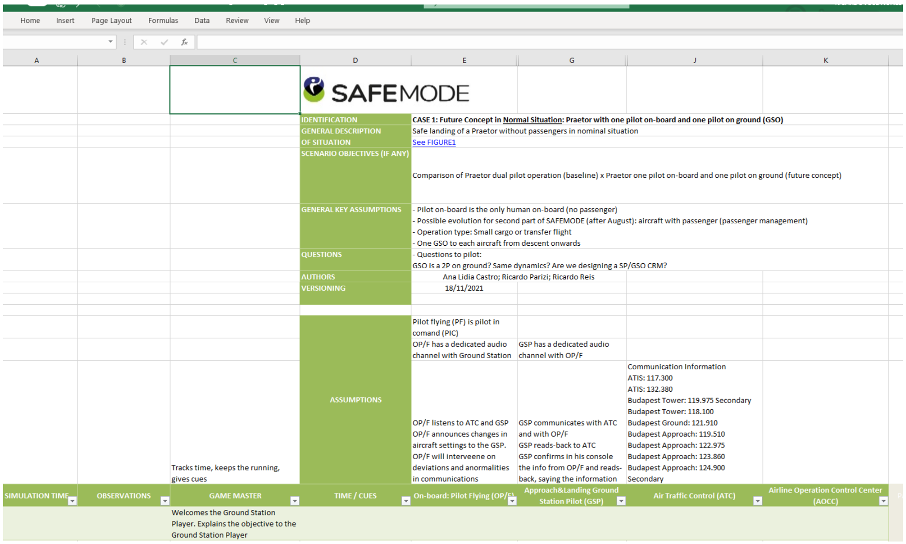


Figure 12: Script header

Under the header, a script table followed (**Fig. 13 Script2**). The main columns used were:

- **Game Master**: specific intervention.
- **Time/Cues**: this helps synchronise the execution of the script and segment the time events.
- **On-board Pilot:** audio lines and cues.
- **Approach&Landing Ground Station Pilot**: expected lines and reactions. Used to support the scripted actors.
- **Cruise Ground Station Operator:** audio lines.
- **Air Traffic Control:** audio lines. This covered the different ATCOs (cruise, approach, tower).

Founding Members

GAME MASTER	TIME / CUES	On-board: Pilot Flying (OP/F)	Approach&Landing Ground S	Cruise Ground Station Opera	Air Traffic Control (ATC)	Airline Operation Control Center (A
		OP/F verifies against console readings			ATC/APP says "Embraer 123, Roger. Report CATUZ."	
	NEXT SLIDE		GSP reads-back "Report CATUZ, Embraer 123."			
	BP774	OP/F informs: "Passing overhead BP774. 8.000ft, speed 230kts and flaps 1 selected."				
	NEXT SLIDE		GSP confirms in console "Checked"			
	CATUZ	OP/F informs GSP reaching 5.000 ft. "Reaching CATUZ position at 5.000ft. Reducing speed to 200 kts and flaps 2 selected."				
	NEXT SLIDE		GSP confirms in console "Checked"			
RED Incapacitation Warning			GSP says to ATC/APP "Budapest Approach, Embraer 123 passing CATUZ at 5.000 ft."			
					ATC/APP instructs "Embraer 123, cleared ILS approach, RWY 13 left, report established."	
			GSP reads-back "Cleared ILS approach RWY 13 left, report established. Embraer 123"			
			GSP tries to contact OP/F "Embraer 123 please report your status. "			Incapacitation alarm appear at AOCC
			(wait ~5s)			
			GSP tries to contact OP/F "Embraer 123 please report your status. "			
			(wait ~5s)			
	NEXT SLIDE		GSP press the incapacitation button (puts the transponder in emergency mode (SQUAWK 7700) and enables full control from ground station) "Console, engage pilot			

Figure 13: Script2 Incapacitation case script extract. Showing game master, events and actors cues. Incapacitation visually indicated by black cells in the On-Board Pilot column.

9.4.3 Console

A representative console was developed to support the simulation. It was developed through a powerpoint slidedeck. Each slide represented a new situation, triggered by the change in position of the aircraft, communication with ATC, aircraft system change, incapacitation, etc. Although greatly simplified for the purpose of the LFS, it followed human factors guidelines and mirrored what pilots would expect in a Ground Station console. Several elements were also taken from the cockpit in order to provide a familiar setting. For instance, the status of systems was conveyed using the same colour code found in Embraer aircraft (Fig. 14).

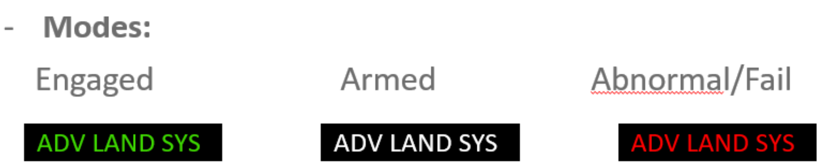


Figure 14 Colour codes for system status.

Due to the limitations of the simulation set-up (i.e., powerpoint slides operated through a virtual conference system), command interactions with the console were made using audio commands: “CONSOLE DO…”. This standard form of request was provided to the pilots but not enforced during the simulation. The game master accepted the different variations used by the pilots in commanding the console, so the simulation flow was not broken. Audio commands would not be the main interaction mechanism in a real scenario.

The console had two main modes (i.e., before initialization and in operation). Console appearance before initialization, i.e., before the flight was transferred from the cruise ground station to the approach and landing ground station, is shown in the picture below (Fig 15).

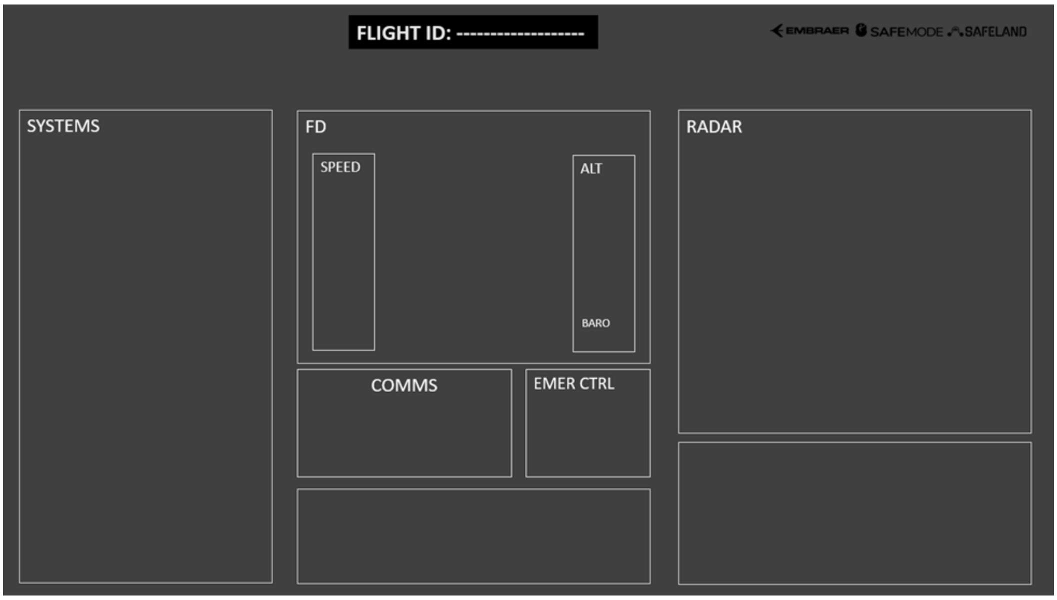


Figure 15: Console before initialization. Only the logical groups are shown, where the information will be found after connection.

After successful connection to the aircraft, the console displays similar information available to the pilot, as shown in Fig. 16. The middle lower box was a text message console, providing system messages and other cues to the GSO. On the top, On-board Pilot and Aircraft communication Link status were displayed. The information in the different regions (e.g., Flight Display (FD), Radar, Text Message Console, Systems Modes, etc) was updated between slides as the simulation unfolded.

Figure 16 Console in operation, after successful connection to the aircraft.

Upon incapacitation, the pilot status indication would go from steady GREEN to blinking RED and the visual indication change accordingly to 

. After the GSO commanded the console to activate the Pilot Incapacitation Emergency Mode, the indicator would be steady and the “Pilot Incap.” emergency control would also turn red.

Each scenario slidedeck had appr. 50 slides. Automated timing was added to the slides, taken from the average velocity and estimated distance flown between slides. The game master could anyway change the slide at any point during the execution.

9.5 Experimental protocol

The Low-Fidelity Simulation was carried out in an online setting using Microsoft Teams as a communication platform, with all the researchers and the participants connected remotely. The steps of the simulation are presented in the following sections.

9.5.1 Briefing

The participants were informed about the Low-Fidelity Simulation methodology with a “*briefing pack*” sent to them via email around 2 weeks before the simulation session.

The briefing pack (see Fig. 17) was organised thematically (i.e., Objectives, Manual, Agenda, Mission, Video Example), and consisted of a slidedeck pdf file and video providing information on:

- the simulation objectives and agenda;

- GSO roles and responsibilities, SPO nominal concept of operations, new procedures, new automation system description (Advanced Landing System) and Ground Station console;
- Mission flight details through charts and aircraft status on start of simulation;
- SPO nominal scenario simulation video.

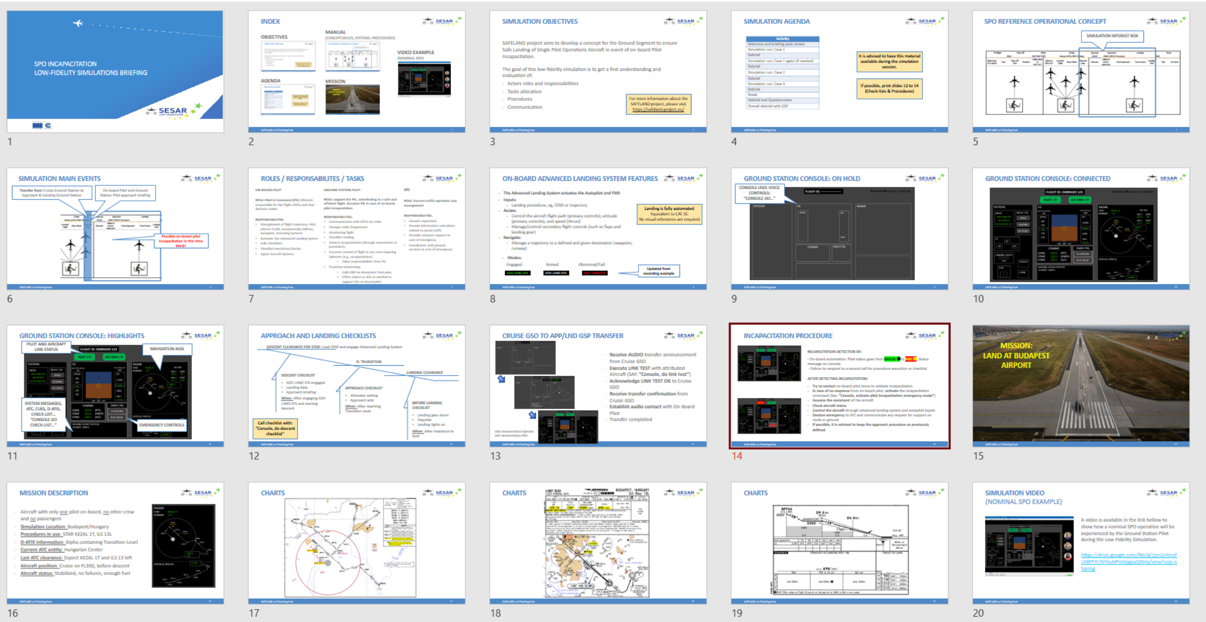


Figure 17: Overall view of the Briefing pack slidedeck.

9.5.2 Experiments Execution

The LFS sessions took place on different days for each participant. On the day of the simulation, the participants were welcomed by the researchers and introduced to the simulation activities with a short presentation. This presentation illustrated the agenda, reminded the participants of their role and responsibilities as GSO, and explained the overall goal of the simulation.

Each LFS session was structured as follows (see also Table 16).

Before the execution of the experimental scenarios, a training session was carried out with the participants of the simulation. The training consisted of executing a non-experimental scenario (Case 1) while trying the simulation console and interacting with the other actors. The training session started with the aircraft entering the TMA and ended after landing at Budapest Airport. The training scenario was similar to the experimental one, with the difference that the participants were experiencing a “nominal” situation, without the pilot incapacitation. In the nominal situation the GSO role was very similar to the role that a pilot monitoring has in current two-pilot operations (e.g., monitoring the flight, assisting the pilot flying, communicating with ATC, reading the checklists). During the training session, the participants acted as the GSO, making decisions, and interacting (by voice) with the Ground Station console and with the other actors of the simulation (i.e., ATCO, Cruise GSO and On-board pilot).

After the training session, a short open discussion between the participants and the researchers was carried out to answer all the questions or doubts that they might have had after the simulation. If needed by the participant, the training session was repeated.

Immediately after the training, the two incapacitation scenarios from the SAFELAND concept were executed (Case 2 and Case 3). As already said in subsection 2.4.2, in both scenarios, participants were required to react to the incapacitation event, assume responsibility for the aircraft, and land it at Budapest Airport from the Ground Station.

Each scenario was around 20 minutes long. After each scenario, a short debriefing session of around 5 minutes was carried out to answer any participants' questions.

At the end of the simulation activities, the link to an online questionnaire was sent to the participants. After the questionnaire, an overall debriefing session was conducted by the researchers. The first part of the debriefing session was dedicated to the semi-structured questions formulated before the simulation, while the second part was dedicated to a discussion between the participants and the researchers (see next section data gathering). The discussion was also based on the observations made during the simulation.

On average, a Low-Fidelity Simulation session took approximately 1h for the simulation activities (Cases 1, 2 and 3), and 90 minutes for the questionnaire and debriefing (see details in the table below).

Session N	Date	Training - Case 1 duration (min)	Training - Case 1 rep duration (min)	Case 2 **Incapacitation within the TMA** duration (min)	Case 3 **Incapacitation under ATC vectoring** duration (min)	Questionnaire and Debriefing duration (min)
1	22/11/2021	10	-	11	13	17 + 100
2	23/11/2021	11	-	12	12	20 + 75
3	24/11/2021	16	11	12	13	20 + 60
4	29/11/2021	12	-	12	13	7 + 60
5	2/12/2021	19	10	12	9	20 + 54
6	3/12/2021	11	-	11	14	20 + 110
7	6/12/2021	11	-	11	13	17 + 60

Table 16: LFS sessions details and durations.

9.6 Data gathering

The methods chosen to carry out the data gathering process included: observations, questionnaires, and semi-structured interviews. Questionnaire and debriefing items were derived by the specific validation objectives generated for the LFS (see section 9.3)

<u>Observations</u>

An observation grid was filled out by the researchers during the simulation session to collect aspects such as thoughts, errors, doubts, and specific behaviours according to the specified categories of research objectives. The motivation was to mark any point of discussion useful for the debriefing session.

Questionnaire

At the end of the experimental scenarios, an online questionnaire was sent to the participants. The questionnaire consisted of 8 close-ended statements that participants were asked to rate on a 1 to 5 scale of agreement, where 1 corresponded to "*Strongly disagree*" and 5 to "*Strongly agree*". Each rating item was followed by an open-ended question where participants had the chance to explain their rating and elaborate on that topic (i.e., "Could you give the main reasons for your answer, and do you have improvement suggestions?") (See table 17 for details).

Investigated areas	Questionnaire items
Roles, responsibility, and tasks allocation	ROLES/RESPONSIBILITIES: After the GSP became the PIC, the GSP was able to perform this role (being responsible for the flight safety).
	TASKS: The task allocation between GSP / Automation / On-board pilot was satisfactory in terms of increasing the likelihood of success of the incapacitation handover.
	TASKS: After the GSP becomes the PIC, the task allocation between GSP and Automation was satisfactory to perform this role (being responsible for the flight safety).
Operating procedures	OPERATING PROCEDURES: I felt the incapacitation procedure, relative to the experienced scenarios, was clear and acceptable (simple, easy to follow, correct order, etc...).
Team and communication	TEAMS/COM: During the incapacitation scenarios, the coordination between ATC and GSP was effective and efficient. The communications were clear, sufficient and on time.
Situational Awareness	SITUATIONAL AWARENESS: Regarding the incapacitation event, I felt I was able to anticipate, plan and execute actions as required for the success of the flight. Namely, I felt aware of the aircraft and airspace situation.
	SITUATIONAL AWARENESS: During the incapacitation scenarios, I felt I had all the information needed, at the proper time, to support my decisions and task execution.
Workload	WORKLOAD: After the incapacitation is detected, I felt the workload could be managed and within the GSP safe performance boundary in a real-life situation.

Table 17: Questionnaire items

Debriefing

The debriefing session consisted of a semi-structured part, where participants were invited to elaborate on different topics based on a prepared interview guideline (see table 18), followed by a discussion session. Topics were related to the specific validation objectives investigated within the Low-Fidelity Simulation and included a set of questions on safety aspects.

The discussion session allowed participants to share any thoughts and opinions with the researchers, raise new topics of discussion not already covered within the questionnaire and the interview, and clarify possible ambiguities about the simulation and the concept experienced.

Investigated areas	Debriefing – Semi-structured interview topics
Roles, responsibility, and tasks allocation	Acceptability of the operational concept Acceptability of roles and responsibilities (prior and after incapacitation) Acceptability of task allocation/More help needed Training needed to be a GSO
Operating procedures	Acceptability of operating procedures
Team and communication	Effectiveness and efficiency of the coordination and communication between on-board pilot and GSO
	Effectiveness and efficiency of the coordination and communication between GSO and ATCO
Technical support systems and Human-Machine Interface	Additional information needed Expectation towards the Advanced Landing System
Situational awareness	Overall SA level and differences between scenarios
Workload	Overall workload level and differences in workload between the experienced scenarios
Safety	Can you identify any other potential hazards for the concept? Propose possible mitigation solutions.
	How do you think the safety of the operations will be affected by loss of communications between GSP and Airplane? What can be done to mitigate the risks of this situation?
	How do you think the safety of the system would be affected by loss of communication between the GSP and ATC? What can be done to mitigate the risks of this situation?
	How do you think the safety of the system would be affected by unforeseen technical failure, for example engine failure, during the incapacitation scenario? What can be done to mitigate the risks of this situation?
	How do you think the safety of the system would be affected by unforeseen meteorological events, such as windshear in final approach? What can be done to mitigate the risks of this situation?

Table 18: Debriefing – Semi-structured interview topics

9.7 Data Analysis

Written and oral feedback derived from questionnaires and debriefings were collected, integrated, and summarised as shown in the next chapter.

Results have been structured as follow:

A first section (10.1 - Concept evaluation) reports the main findings related to concept evaluation. Results are divided into three categories, following HP Assessment Arguments (i.e., Arg. 1 Roles, Responsibilities, Operating Methods and Human Tasks, Arg. 2 Technical Support Systems and Human-Machine Interface, Arg. 3 Team Structures and Team Communication).

A second section (10.2 - Hazards identification) reports participants' feedback on safety aspects

A final section (10.3 - Contribution to RTS) discusses how LFS will contribute to RTS.

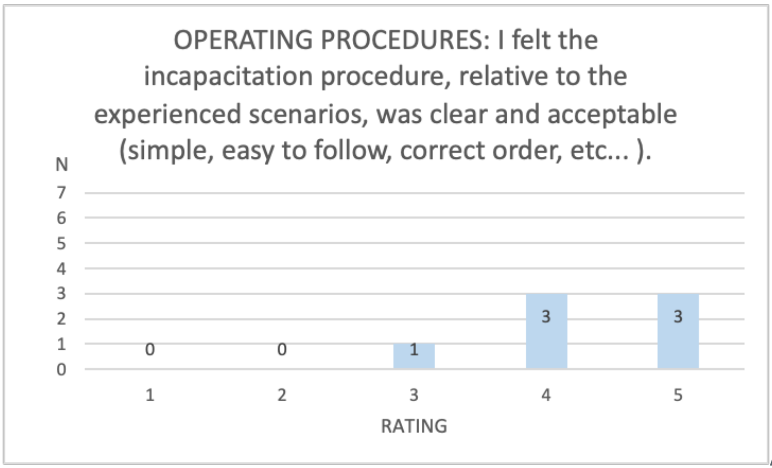
10 Results

10.1 Concept evaluation

This section reports participants' feedback divided into three categories, following the HP Assessment Arguments. Results include plots and a textual part. The plots have been derived from the rating answers provided by participants in the online questionnaire. The text combines the questionnaire open-ended answers related to that rating (i.e., "Could you give the main reasons for your answer, and do you have improvement suggestions?") and feedback on that topic collected during the debriefing. Note that not every topic of discussion covered during debriefing was associated with a rating item in the questionnaire. Each subsection includes a summary of these considerations as well.

Raw data from questionnaires and debriefings are reported in Appendix A.

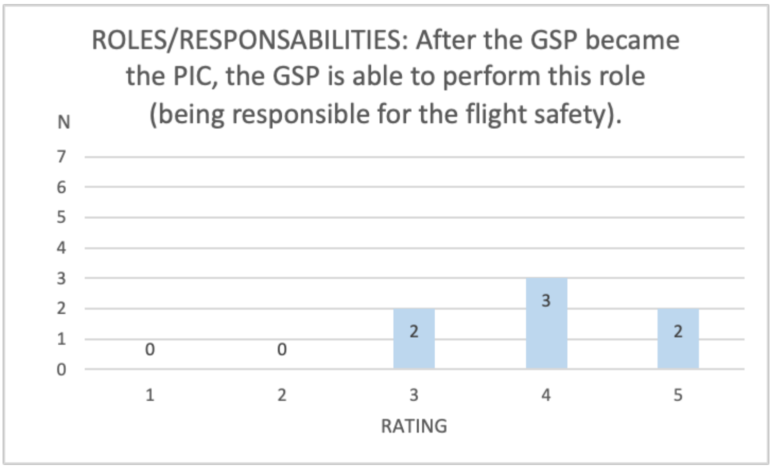
Roles, responsibilities, operating methods, and human tasks



AVERAGE= 4.3

Participants' evaluation of the **operating procedures** envisioned by the SAFELAND concept returned positive results, with ratings from "neutral" to "strongly agree, as shown by the plot above. In follow-up answers and during debriefing, some participants expressed that they fully understood and appreciated the procedures in place, that they were able to perform in an accurate, efficient and timely manner. Other participants were less comfortable with procedures, arguing for more training required, more clear GSO-OBP communication procedures and more clear rules of engagement of the GSO (in case of a failure of the automatic incapacitation detection system). One participant proposed the introduction of decision making procedures (such as DODAR or FORDEC) to better handle the emergency. It is straightforward that the introduction of such practises would require time, and, depending on flight phase, it could lead to e.g., a holding manoeuvre (see SA section). Other participants rejected this vision, prioritising the opportunity of landing as soon as possible.

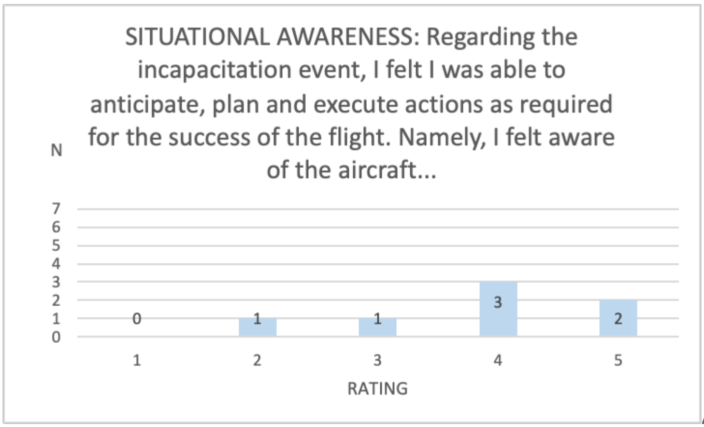
During debriefing, participants were asked to evaluate the acceptability of the GSO role in nominal flight conditions (i.e., Case 1). The **responsibilities associated with the GSO role in nominal conditions** have been positively evaluated by LFS participants. The communication with ATC and the interaction with the OBP (supported by the permanent audio connection between Ground Station and cockpit) were perceived as beneficial to maintain a sufficient level of situational awareness and avoid boredom. Two participants claimed that a more "passive" role (GSO not communicating with ATC and only monitoring the flight) could also be acceptable, and, for one participant, even preferable, but this condition could affect the readiness to assume control of the aircraft after OBP incapacitation or to deal with other emergency situations.



AVERAGE= 4

The **responsibilities associated with the GSO role after incapacitation** has been also considered acceptable by the involved participants, as shown by the plot above. Nevertheless, it was broadly recognized that the acceptability of the role is strictly dependent on the reliability of the automated systems foreseen by the concept and of the communication link. A participant pointed out that, "*to make the system trustworthy and the GSO responsibilities acceptable, the failure rate must be around 10e-7*". Responsibility and liability issues could arise in case of technical failures (e.g., C2 link loss).

All participants agreed that a specific training is needed to perform the GSO role. Moreover, to ensure a high level of safety, the GSO **knowledge, skills and operational experience** should be similar to those required for a pilot. A participant suggested that alternating pilot flying and GSO roles would help in maintaining handling skills, mental flexibility, and motivation.



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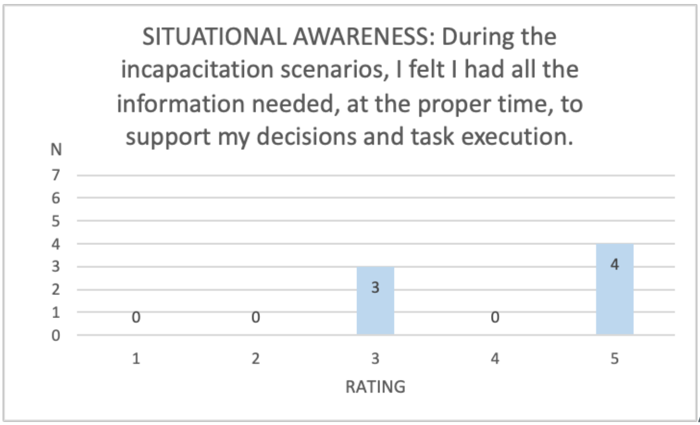
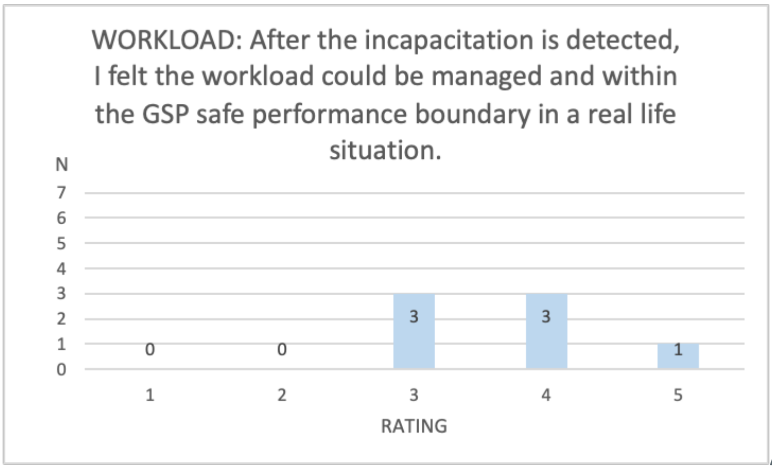


AVERAGE= 4.1

As shown by the first plot above, participants' evaluation of their level of **situational awareness** returned mixed results. One participant reported lack of sufficient training with console and procedures, and another claimed that, in case of incapacitation, an extra person at the Ground Station would be helpful to handle the emergency. Three other participants (see also second plot) expressed the need for more information shown on the console in order to anticipate, plan and execute the actions required for the success of the flight, or more time to build situational awareness. In a real deployment, time to gain SA could be achieved by entering a holding procedure, declaring a go around, or having in place an automated system slowing down the aircraft to minimum clean speed immediately after incapacitation is detected. Other participants rated their level of SA higher, due to the support of Incapacitation Emergency Mode and Advanced Landing System, giving them some spare capacity by performing aviate actions and some emergency procedures. Information displayed on console and ATC support were considered sufficient to support GSO's decisions and land the aircraft safely.



AVERAGE= 3.7

As described by the plot above, participants' **workload evaluation** returned mixed results, with a positive trend. Follow-up answers and debriefing discussion returned that, albeit perceiving as slightly different, the levels of workload (WL) entailed by the two incapacitation scenarios (Case 2 and 3), four participants evaluated both of them as acceptable (e.g., "WL level in Case 2 and 3 was similar", "WL was okay", "Radar vectoring scenario (Case 3) had a higher workload, but it was not a problem"). Three participants, instead, reported that the higher WL in the vectoring scenario (Case 3) could affect the safety of the flight and, therefore, the whole vectoring procedure should be avoided. Possible solutions proposed to mitigate such risks could be having an extra person on the ground supporting the GSO (this mitigation was proposed also to deal with other possible failures) or returning to the closest waypoint in order to have the Advanced Landing System back to functioning and proceed with an automatic landing.

Technical support systems and Human-Machine Interface

The information displayed on the console is very important for the GSO to gain SA, quickly assess the situation and deal with the incapacitation scenario. According to one participant, analysing the situation from the ground compared to the cockpit could even represent an advantage.

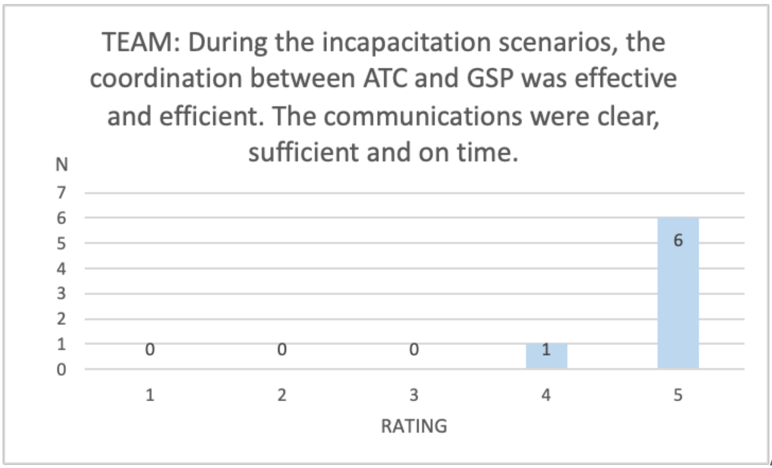
Regarding the **type of information provided by the HMI**, most participants agreed that the Ground Station resources should basically replicate what the pilot has in a real cockpit. Participants expressed two different requirements: on the one side, more information was needed regarding the health status of the OBP, on the other more information was needed regarding the status of the aircraft. The latter could also help in understanding the possible causes of the incapacitation (e.g., depressurization). The additional information required to be provided on the console included: fuel on board, reserve fuel to the selected alternate airport, Flight Mode Annunciator (G/S capture, LOC capture), engine power, track miles or distance to the runway, weather radar, airspeed indicator, complete PFD and ND (Navigation Display). Such additional information could be shown on a second console display, in order not to overfill the main one "*It could be useful have more information and this could be displayed on a second page, what I would not do is to fill-up the first display with all the information for a GSO not doing this job everyday, so in case of relevance or to know something else maybe you can switch to another page…*" (Subject 6).

Regarding **how** some pieces of **information were displayed**, some participants found difficulties in following the sequence of information or tasks (e.g., checklists) coming and going on the console proposing to (i) "*make things blinking when they change, or (ii) include a different square around the things that are changing*", or (iii) display armed and active items in different colours and, in case of upcoming tasks, showing "what's next". Moreover, it was proposed to 1) add an acoustic cue to the visual incapacitation alert, 2) make the incapacitation alert and incapacitation button closer or the same button, 3) include an indication of who is talking with the GSO (i.e., ATC or OBP), to avoid possible confusion. Some of these suggestions will be implemented in the RTS platform (see section 10.3 Contribution to RTS).

When asked, six participants agreed that a **camera** giving an inside view of the cockpit would be beneficial to check/monitor the pilot's health in case of an incapacitation (e.g., "could be that there is a wrong detection and maybe it is only his microphone that is broken. It would be nice if you have an additional way of verifying that the pilot is really incapacitated"), but not strictly necessary in nominal operations. Similarly, for four participants a camera giving the outside view would represent an added value, but it is not considered essential, given the high level of automation already foreseen by the concept and considering that today it is already possible to land with low visibility.

Finally, participants expressed concerns about the console voice control, considering manual control as preferable. Nevertheless, this feature was just an adaptation related to limitations of the low-fidelity methodology.

Team structures and team communication

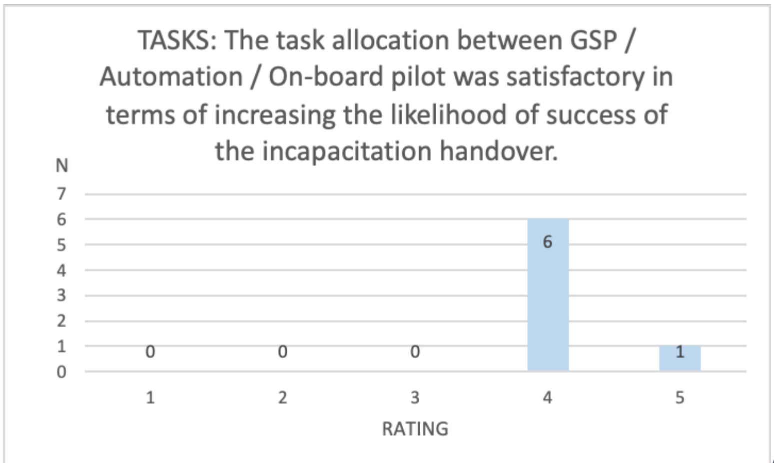


AVERAGE= 4.8

All participants agreed that the **communication flow and the coordination with ATC** was very good, communications being clear and timely and coordination being effective and efficient. As expressed during debriefings, the expectation is that ATCOs, knowing the standard procedures to be applied in case of an incapacitation and knowing the behaviour of the aircraft once the incapacitation mode is selected, will clear the surrounding traffic, advise the landing airport, and help the GSO upon request. Four participants expressed concerns about the communication load, evaluating it slightly excessive, giving the emergency situation

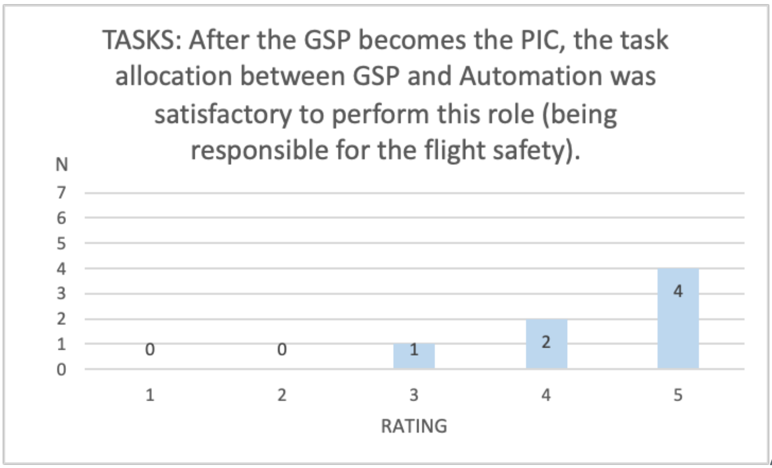
"The pilot needs to prioritise… aviate, navigate, communicate… so communicate is the lowest priority… If I declare emergency I don't need ATC anymore… I know that they are clearing all the traffic all the way, so you need to do what you need to do anyway…" (Subject 4). All participants agreed that switching frequency from approach to tower control should be avoided, to reduce GSO workload.

Regarding the **communication flow and coordination with the OBP** (in nominal conditions), participants generally expressed a positive evaluation. Nevertheless, they reported the need for more precise communication procedures and standard phraseology. Readback was perceived as excessive but necessary, due to the pilots (i.e., GSO and OBP) being in different locations. On a technical side, one participant expressed concerns about the possibility of finding new frequencies in Europe to provide the open channel between the GSO and the OBP.



AVERAGE= 4.1

As shown in the plot above, **Task allocation** was positively evaluated by all simulation participants. It was broadly agreed that the responsibilities associated with the GSO role (e.g., monitoring the flight and communicating with OBP and ATC) would increase the likelihood of success of the incapacitation handover compared to a situation where GSO and other actors are not actively interacting. At the same time, all participants recognized the predominant role of automation (specifically, Incapacitation Emergency Mode and Advanced Landing System) in helping the GSO to safely land the aircraft. When asked, participants recognized that having the AOCC helping the GSO upon request would represent an added value, especially to deal with specific scenarios (e.g., bad weather in the area).



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Focussing on the role of automation, participants positively evaluated the **task allocation between GSO and automated systems**, considering the proposed solution a safer option compared to manually flying the aircraft from the ground. Nevertheless, it was pointed out that such a system requires a high level of trust towards the automation itself and automation to be transparent. Participants expected the Incapacitation Mode button to disable the on-board controls and enable commands from the ground, treating the aircraft as a UAV. Regarding the Advanced Landing System, participants appreciated the automatic actuation of landing gear and flaps, evaluating the whole autoland system as a possible great improvement compared to today's automation for commercial aircraft. On the other hand, they acknowledged the importance of the monitoring role of the GSO to guarantee the safety of the flight.

Among the suggestions proposed by participants to improve the system, some pilots mentioned that, once incapacitation is detected, the system should revert to the highest possible level of automation, slowing down the aircraft in order to give the GSO time to understand the situation. Another participant suggested that an even more advanced system could analyse the situation, generate options, and propose the best ones to the GSO. In case of link loss between the aircraft and the GS, participants agreed in saying that the automation would be expected to land the aircraft without receiving any inputs from the ground, and, if necessary, even autonomously perform a go-around procedure.

Operational Concept feasibility

Overall, the **SAFELAND concept** of operation was perceived as acceptable by the involved participants due the combination of a conservative approach (being the OBP and GSO a two-pilot crew) with technologically advanced features already in place in non-commercial aviation (e.g., UAS operations). Nevertheless, it was broadly agreed that its feasibility would be strictly dependent on advancement and trust in automation and reliability of the data link communication. Technological challenges, cyber-security and data link issues were pointed out as the major possible showstoppers (see next section).

10.2 Hazards identification

Although the LFS participants did not experience any other emergency or failures apart from the incapacitation event, at the end of the debriefing they were asked to identify any other potential hazards for the concept and propose possible mitigation solutions. Following, a summary of results is provided, with hazards divided into macro-categories (see Appendix A for details).

Technical failures

When looking at the main points mentioned regarding **system failures** during the LFS, threats included were single and multiple failures amongst which emergency descent, engine failures, and more severe failures such as dual engine failures. The mitigation necessary to manage such failures included multiple GSOs being present to avoid adding risks to the operation by overloading one GSO. Moreover, it was mentioned that increased automation levels might be useful to initiate necessary procedures in time critical situations such as an emergency descent.

Another threat mentioned during the simulations was based on the **failure of the pilot incapacitation detection system**. To mitigate this, the system needs to have redundancy and be fail operational. It was also mentioned that having cameras on board that activate when a potential incapacitation is detected would be a great advantage to confirm the health status of the pilot.

Communication

Regarding communication, the main risk mentioned was the **loss of data link between the GSO and the aircraft**. The communication failure between the two would require systems in place to make the plane able to autonomously follow the flight plan when failure is detected. Having multiple data link connections available would also create redundancy helping to mitigate the risk. Standard procedures for such failure should be developed. For instance, an automatic squawk setting should be implemented to advise ATC units of GSO-aircraft communication loss. It was also mentioned that, when a link failure is detected, there should be an automatic ATC notification that the aircraft automatically will continue to follow the pre-programmed flight plan until landing. Airport selection should also be automatic, based on pre-set criteria. Also, the pilot incapacitation emergency mode would require automatic activation in case GSO is unable to activate it, where sensors on the pilot would trigger system activation.

Link loss between GSO and ATC was also considered as a risk to safe operations, with possible mitigations. The mitigations included normal land line communication or text messages like CPDLC.

Cyber security was considered as an important risk area. The main concern regarded the risk of a possible interference of the GSO with no pilot incapacitation. To mitigate this, an inflight override system must be in place in case of attempted hostile take over from the GSO. The risk of external interference also exists which might require multiple stable connections between GSO and the aircraft.

Miscellaneous threats

Many participants recognized that **environmental or external threats** such as adverse weather or blocked runways can have a considerable impact on safety. ATC being proactive when dealing with a single pilot incapacitation would mitigate some risks. For instance, ATC can help with the airport selection, or contribute to increase situational awareness of the GSO. On ground incursions could also be included as a risk, where ATC systems such as ground radar being available to the GSO can increase the safety of the operation.

To reduce risks in terms of GSO competencies, having a GSO who is a certified pilot would highly increase safety.

Threats such as **high workload** of GSO leading to potential high energy approaches can be mitigated by the advanced landing systems ability to bring the aircraft to minimum sector/procedural altitudes as early as possible. If a high energy approach leads to a go-around procedure, the threat of automation capabilities becomes a factor. External control of the aircraft for a phase of flight as critical as the go-around requires the automation to be able to execute the procedure autonomously, similarly to a STAR or SID.

10.3 Contribution to RTS

If on the one side the LFS provided a first evaluation of the feasibility and validity of the SAFELAND concept, on the other the process that led to the development of the LFS tool, together with the feedback collected from participants, contributed to the refinement of the RTS environment and scenarios, and to the execution of the RTS itself.

Specifically, the following aspects of the RTS benefit from the LFS execution:

- RTS scenarios and scripts
- Technical support systems and HMI
- RTS execution
- RTS data gathering

Scenarios and scripts

The LFS tool development and the LFS execution contributed to create a better understanding on specific simulation aspects and features. In particular, the creation of the scripts shed light on details of the procedures to be followed during the simulation and on coordination and communication aspects among the different actors involved in the scenarios. These details will be taken into consideration for the refinement of the RTS scenarios and scripts.

Technical support systems and HMI

Participants' feedback on the type of information available and on how this information was displayed on the LFS console revealed that an ideal Ground Station should basically replicate what the pilot has in a real cockpit. The additional information required to be provided (see section 10.1 - Technical support systems and HMI) included: fuel on board, reserve fuel to the selected alternate airport, Flight Mode Annunciator (G/S capture, LOC capture), engine power and status, track miles or distance to the runway, windshear information, weather radar, airspeed indicator, ground proximity warning, complete PFD, and Navigation Display. Apart from the weather radar, the wind shear information and the ground proximity warning, all other information will be present in the RT Ground Station simulator. Regarding how some pieces of information were displayed, it is worth noting that some of the features of the console used by LFS participants won't have any correspondence in the RTS environment, being the latter much more sophisticated and realistic. Many of those features must then be considered limitations of the low-fidelity methodology. However, some functions will be implemented, such as the acoustic cue to be added to the visual incapacitation alert. Other possible functions/tools mentioned by participants (i.e., cameras giving inside and outside view, or an indication of who is talking with the GSO) won't be implemented, but their usefulness will be taken into consideration as a debriefing topic of discussion.

RTS execution

Since the SAFELAND concept is introducing many variants compared to current two-pilot operations, both the briefing pack and the training were considered crucial by LFS participants. For this reason, an ad hoc briefing pack for the RTS will be created based on the structure of the LFS one and sent to participants before their session. The briefing pack will include slides with a description of new roles, procedures, and systems, and a SPO nominal scenario simulation video.
Regarding training, two possible solutions could be implemented to make participants familiar with the SAFELAND procedures: a scenario where the GSO is monitoring a nominal SP flight (OBP is the PIC) and a scenario where the GSO is controlling a nominal SP flight (GSO is the PIC).

RTS data gathering

The data gathering methodology that will be used during the RTS will be very similar to the one used during LFS. Therefore, many of the LFS questionnaire and debriefing items will be reused or slightly adapted for the RTS participants. Moreover, the new issues and topics emerged during the LFS debriefings will be also included as topics of discussion.

11 Conclusions and next steps

Overall, the LFS addressed all the key validation objectives of the simulation. It allowed a preliminary evaluation of the SAFELAND concept, regarding its operational feasibility, human performance, and safety aspects.

The participants of the LFS recognized the value of the activity in assessing the concept. Despite the limitations of the console slide deck, the level of engagement was perceived as high by involved participants and the LFS was considered a valuable tool for a first understanding of the new procedures introduced by the SAFELAND operational concept.

From the LFS, new points of discussion were identified, which would be useful for the next project's activities. Regarding safety, the LFS allowed a high-level evaluation of the safety implications of the concept. Finally, the LFS enhanced the likelihood of an acceptable outcome from the SAFELAND project, helping to frame the next activities on a stronger basis (e.g., the RTS), together with enhancing the overall productivity of the development process.

The results of the LFS activity will be combined with the next evaluation activities, including:

- RTS
- Workshops with internal SMEs aiming at further assessing the safety, legal, regulatory, and economic aspects related to the SAFELAND concept
- Workshop with internal and external SMEs (i.e., the SAFELAND Advisory Board) aiming at discussing the results of the evaluation activities and collecting final feedback and next steps towards implementation.

12 References

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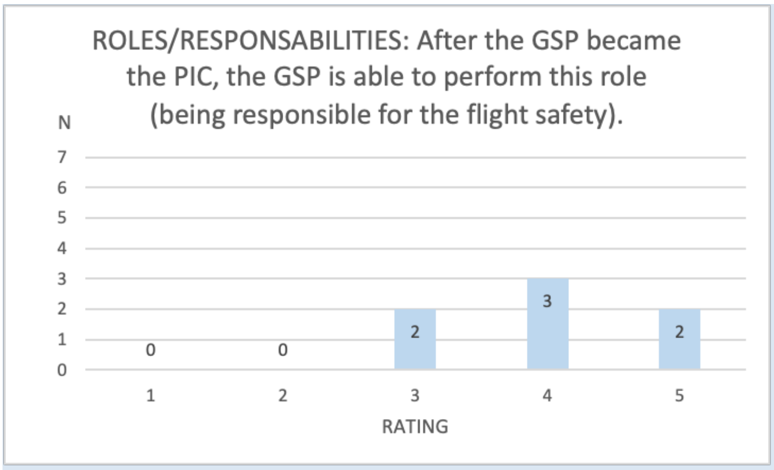
SAFELAND Project (2022b). *Adaptation of Cockpit simulator*. SAFELAND D2.2.

SAFELAND Project (2022c). *Adaptation of Remote Cockpit simulator* SAFELAND D2.3.

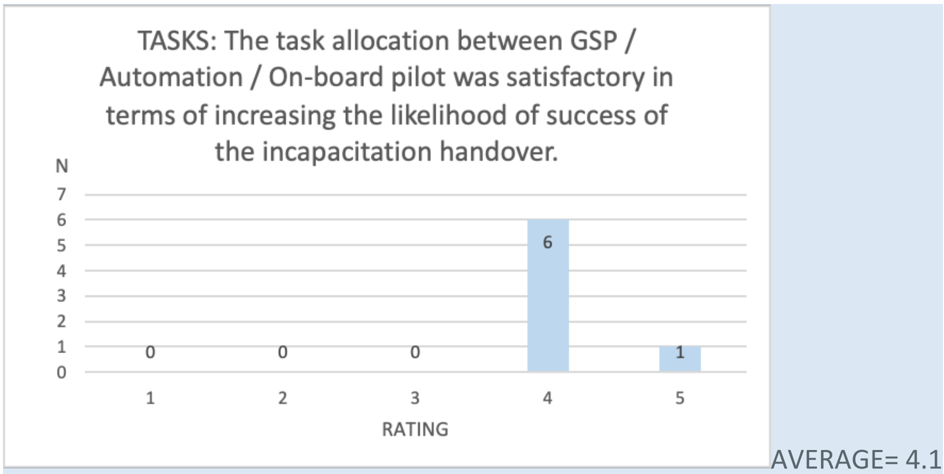
Appendix A Results

A.1 Questionnaire results

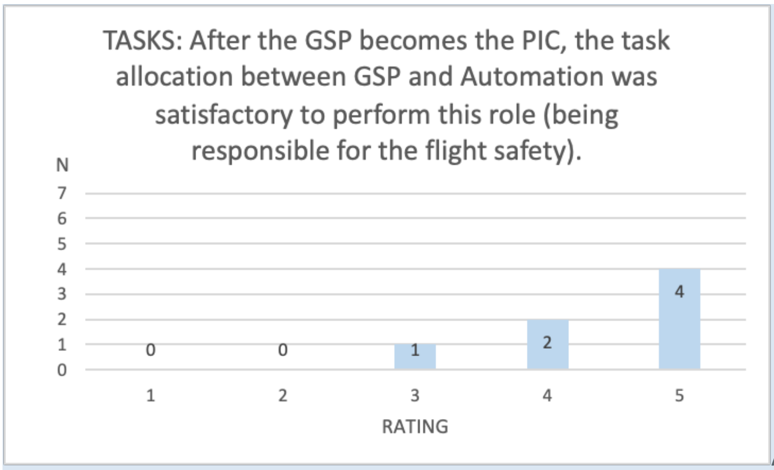


AVERAGE= 4

subj	rating	ROLES/RESPONSIBILITIES: After the GSP became the PIC, the GSP is able to perform this role (being responsible for the flight safety). Could you give the main reasons for your answer, and do you have improvement suggestions?
1	4	It is possible to control the aircraft which is the most important thing. I did not select strongly agree, because it is a little bit difficult to have a full overview of what is going on in the aircraft.
2	5	The SOP are well structured to allow the GSP to perform the role safely
3	4	The Console with Advanced Landing System is working well and very intuitive. I would like to have more information regarding the status of the a/c. Sometimes it is faster to check the information instead of talking with console for one instruction per time. This voice instructions can be overlapped by communication with ATC. In this case an expert professional pilots can look for some information and take a decision quicker than just asking any single item to the console. Some of the information that should be visible are: fuel on board, reverse fuel to alternate and selected alternate, Flight Mode Annunciator (G/S capture? LOC capture?), Engine Power, Track Miles or distance to the runway.
4	4	Automation does most things
5	3	Being responsible for the flight needs a high probability of success. I do not know, just talking to the "Console", whether this system is that reliable. I cannot do anything than hoping that the ADV LAND SYS comes back on. So, there is a lot of trust needed. The failure rate must be around 10e-7 to make this trustworthy - and me responsible.
6	5	GSP was able to fly the aircraft with commands to the console, so it worked well.
7	3	Improved briefing (from my end) would have been useful. I only fully understood my tasks after the first trial run.

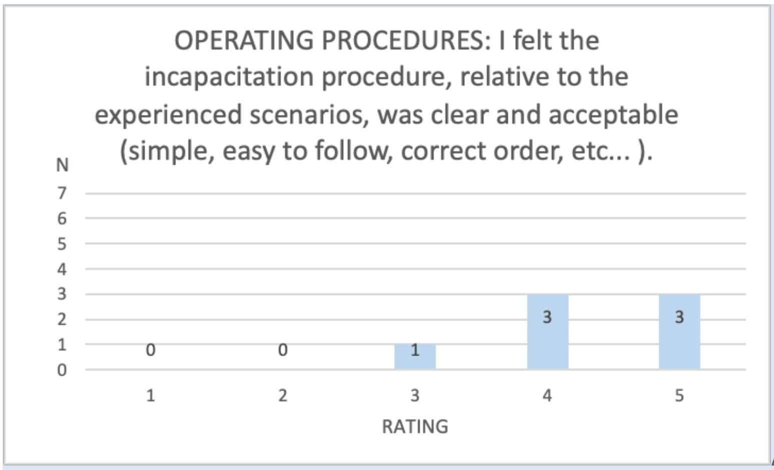


subj	rating	TASKS: The task allocation between GSP / Automation / On-board pilot was satisfactory in terms of increasing the likelihood of success of the incapacitation handover. Could you give the main reasons for your answer, and do you have improvement suggestions?
1	4	It is reasonable that the automation is controlling the aircraft and that the GSP is monitoring the status, entering data and communicating with ATC in case of an incapacitation.
2	4	Once you activate the pilot incapacitation emergency mode the console takes care of ac configuration and flight path, this improved the spare capacity of the GSP
3	4	To handover controls and have a clear idea of what is going on, it might be needed some time. Automation could slow down to minimum clean speed in order to give some extra time. This mode can be activated as soon as the pilot incapacitation is detected. For the rest, everything was very easy.
4	4	The allocation was ok
5	4	There were only very limited tasks to be shared. If everything works fine, it is satisfactory.
6	4	Handover worked without problems. Only the standard callouts are not exactly defined how the read-back should be between OBP and GSP.
7	5	I have nothing to add. I believe the procedures seem easy enough to be fool proof.



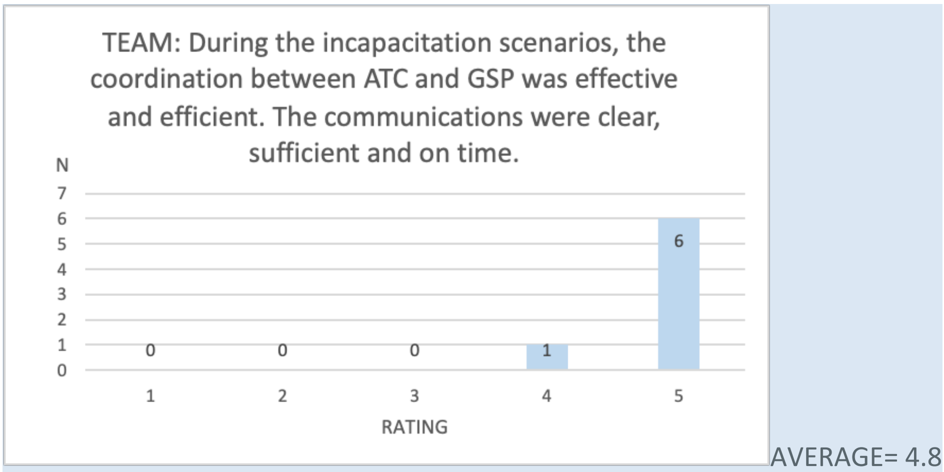
AVERAGE= 4.4

subj	rating	TASKS: After the GSP becomes the PIC, the task allocation between GSP and Automation was satisfactory to perform this role (being responsible for the flight safety). Could you give the main reasons for your answer, and do you have improvement suggestions?
1	5	I think it is not a good idea to manually control the aircraft from the ground, because of missing impressions (weather etc.) Therefore, I think the safest course of action is the use of the advanced landing system controlling the aircraft.
2	5	Once you activate the pilot incapacitation emergency mode the console takes care of ac configuration and flight path, this improved the spare capacity of the GSP.
3	5	Considering only this scenario, without any other variable, the situation was safe. The only extra points required are as discussed in point 2 above.
4	5	Not many additional tasks to do for the GPS
5	3	I did not know if the ADV LAND SYS would come back on. If that was to be used in real life, one should know the limitations of the automation (console).
6	4	Task allocation was ok between GSP and Automation. Maybe in the console info box, we could display not only the actual task right now, below a solid line we could display the next tasks coming to have an idea what will come next.
7	4	Flying the airbus, I believe the aircraft more often than not knows best. If properly configured from within (or by the GSP) it could be trusted to follow the approach to an autoland without outside influence other than monitoring the system.

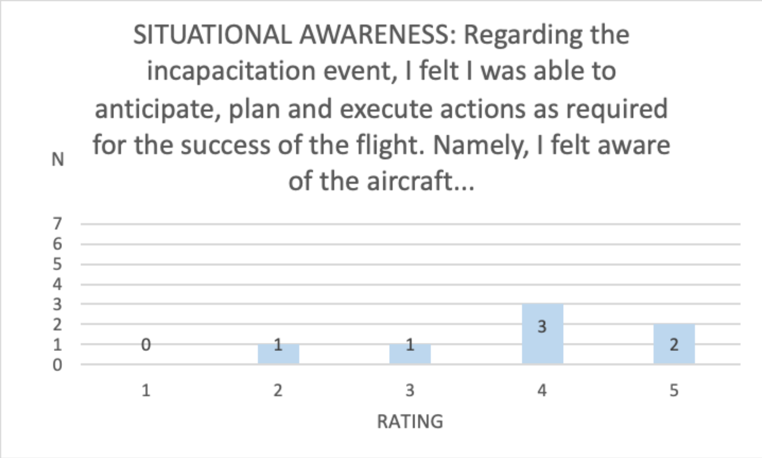


AVERAGE= 4.3

subj	rating	OPERATING PROCEDURES: I felt the incapacitation procedure, relative to the experienced scenarios, was clear and acceptable (simple, easy to follow, correct order, etc...). Could you give the main reasons for your answer, and do you have improvement suggestions?
1	4	It would be great to have visual confirmation of the incapacitation. Otherwise, the procedure is clear and easy.
2	4	Yes it was straight forward form my personal standpoint, I guess is just a matter of get use to the procedure and callouts
3	4	Yes, the situation was easy and could be easily followed. A voice or sound could be useful instead of only a red light. This may avoid distractions that can slow down the process. Like if the autopilot is disengaging, would be useful to have a voice call from automation or a bell or something similar to help detecting the incapacitation.
4	5	it was very clear
5	5	It was clear because a button was pushed by the pilot. But in real life, an incapacitation comes slowly and slowly increases. And nobody knows when one's own limit is reached. It is like getting overweight. When is it enough? When is it too much? So, the challenge is not the 5-star red blinking light, but the pilot on when to push the button.
6	5	As it would be possible in real-life, we had the cases with engaged navigation mode and manual with a heading, so this is ok. What we did not have are other failures to handle or wx on the route.
7	3	Coming from an airline we follow our own procedures, based closely on Airbus procedures. However, following pilot incapacitation, following the manufacturer procedures should be good enough. Naturally depends on whether the Ground Station is manned by a company pilot or by a "random" pilot not aware of company procedures.



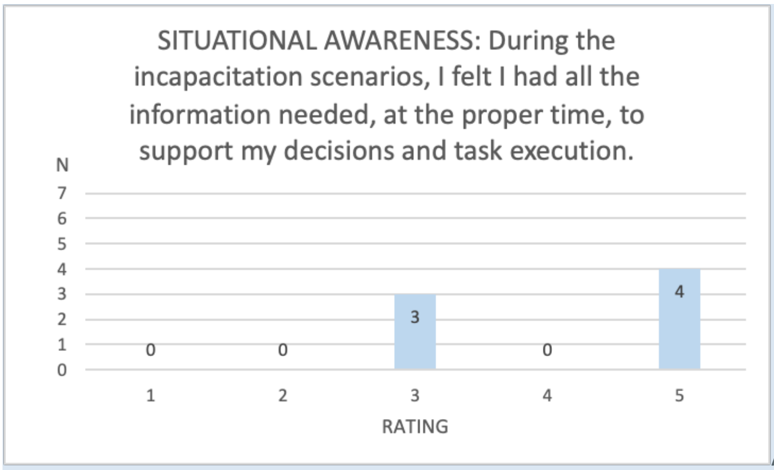
subj	rating	TEAM: During the incapacitation scenarios, the coordination between ATC and GSP was effective and efficient. The communications were clear, sufficient and on time. Could you give the main reasons for your answer, and do you have improvement suggestions?
1	5	The communication did not change compared to flying in the aircraft. I think it would be good to have recommendations (procedures) on hand for the GSP and ATC in case of an incapacitation and a control of the aircraft from the ground. For example, it might be wise to avoid bad weather and turbulences or to avoid overflying cities just because it is more difficult to estimate the situation in the aircraft remotely and to know exactly what is going on.
2	5	The communication between ATC and GSP depends only on Pilot experience
3	4	Yes. Although if on the approach, some information requested, like fuel and time remaining would not being appropriate as I'm concentrating on landing, workload increase as I'm starting to think of what I should do next and what is missing. Obviously, on final approach there should be more silence.
4	5	Communications were as they would be in a present day, dual cockpit emergency
5	5	In an emergency, I expected ATC to do what I wanted. So, I did not think there was any communication of the scenario necessary. In an emergency, ATC and the airport expect for the worst anyway. Preparing the airport, runway, etc.
6	5	ATC helped the GSP as far as he could.
7	5	All comms were clear and on time. All requested assistance provided



AVERAGE= 3.8

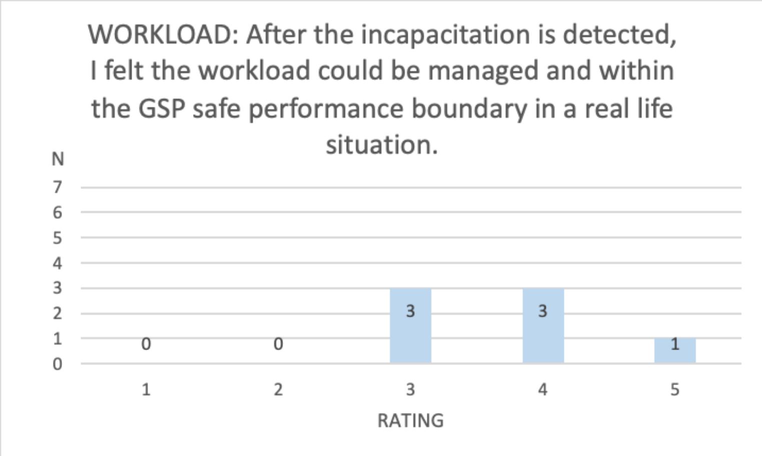
subj	rating	SITUATIONAL AWARENESS: Regarding the incapacitation event, I felt I was able to anticipate, plan and execute actions as required for the success of the flight. Namely, I felt aware of the aircraft... Could you give the main reasons for your answer, and do you have improvement suggestions?
1	4	Procedures would be very helpful for the GSP. Also ATC procedures. Furthermore, it would be helpful to have a second person on ground for support and double check in case of an incapacitation. So, a second GSP would be very helpful in case of an incapacitation.
2	4	The experience of the GSP is the only factor that influences the situational awareness, the ADV LAND SYS improves the spare capacity and consequently will be easier to have a good situational awareness
3	3	Some extra information visible like track miles to the runway, fuel on board. Although this information can be derived by console requests, it is easier and faster to look at that information.
4	5	How to initiate the descent while on vectors was not clear. There is no vertical speed button, for example, or no possibility to "pull altitude" like in airbus
5	5	To stay on a standard "STAR" is better for the situational awareness and for the automation to remain. So that one knows where the aircraft is headed and what to expect.
6	4	In general, yes. With the "PFD" and the chart/profile displayed you have a good situational awareness. The only thing I mentioned already above would be a solid line in the console box with the next coming steps to always be one step ahead of the aircraft.
7	2	Only because it's the first time I "flew" this sim. I'm not familiar with speeds/procedures/airspace, etc. Didn't feel very confident, but it seems like any pilot could help bring this aircraft to a safe landing with enough training.

Founding Members



AVERAGE= 4.1

subj	rating	SITUATIONAL AWARENESS: During the incapacitation scenarios, I felt I had all the information needed, at the proper time, to support my decisions and task execution. Could you give the main reasons for your answer, and do you have improvement suggestions?
1	3	Reason for incapacitation would be great. Information about the condition of the pilot would be great. Is he or she still alive? Information about aircraft status would be needed.
2	5	You have quick access to all the information you need from ATC (environmental) and Console (aircraft)
3	3	Some extra information visible like track miles to the runway, fuel on board. Although this information can be derived by console requests, it is easier and faster to look at that information.
4	5	Maybe radio communication with other aircraft would distract the GSP some more and add to his/her workload
5	5	Easy environment, clear STAR, all charts available. I just needed to know when the ADV LAND SYS would come back on. If it was coming back on.
6	5	I had the information I needed.
7	3	During an approach I like to know tracks to go in order to better plan my descent. Especially during radar vectors. Also, I'd like all the information we normally have on our PFD, rates of descent for instance. I guess during the low-level sim it isn't a requirement, but it would help feel more in control of the aircraft.



AVERAGE= 3.7

subj	rating	WORKLOAD: After the incapacitation is detected, I felt the workload could be managed and within the GSP safe performance boundary in a real-life situation. Could you give the main reasons for your answer, and do you have improvement suggestions?
1	3	I think it would be safer if two GSP could handle an incapacitation situation together. One could focus on the analysis of the situation and identification of operational options and risk and the other one could focus on controlling the aircraft and communicating with ATC.
2	3	I don't have a clear opinion about that, the fact that I'm restricted to a screen is unusual to me.
3	3	Workload became high quite quickly, especially on radar vectors as I had to think about aircraft vertical profile as well. Some weather avoidance could have increased the workload as well as some places where for terrain they tend to keep you high and let you descend after. This scenario of High Energy Approach prevention could have increased the workload.
4	4	Radar vectors and descent procedure for the GSP is unclear.
5	4	Just return to the previous arrival and continue as briefed before.
6	4	In general, yes, I had everything to handle the incapacitation. One thing I would now suggest after acting as GSP is to have the emergency mode activation button next to the red incapacitation info flag because my eyes were concentrated on the red button and another button next to it would be very useful.
7	5	I believe the workload can definitely be managed given pilot incapacitation in SPO, as long as the aircraft is able to do it. Workload right after pilot incapacitation should be highest, but it all depends on when it is detected. If during the descent, a GA could be the best option to gain some time.

subj	Any other general comments?
2	The success of this new technology depends on well structure SOP, the communication between the GSP and the aircraft must be clear and easy to perform, the only weak link I can see is the impossibility for the GSP to communicate and aviate correctly and expeditiously with the AC
3	I think it should be clearly stated what information both pilots should pass to each other. Once the incapacitation mode is activated, the automation could revert straight away to some sort of easy scenario, giving or showing some information immediately as these are expected information from the GSO. So, when pilot incapacitation mode is on, automation can already be activated in order to

	highlight important information to GSO and to revert to the highest level of automation capable, eg. activate the Advanced Landing System.
5	- Incapacitation is hard to detect by oneself, so two pilots are much better than one. Here in that scenario the recognition of the incapacitation was clear (red light). In real life it is very subtle. - I do not think that one person on the ground is able and responsible for an aircraft with passengers just via a ground station. They might come (like with military drones), but we need full risk assessment with the lowest probabilities. - I would see other solutions first. Like having a flight attendant with limited flight training to accompany the approach and landing.

A.2 Debriefing results

Subj N	Roles, responsibility, and task allocation – Acceptability of the operational concept
1	Overall, the concept is acceptable. Flying manually from the ground would not be acceptable. High levels of automation required.
1	Responsibilities of GSO role are acceptable
2	The concept works.
2	SPO feasible only with advancement of technology
3	The concept is acceptable but console needs improvement (more information displayed)
4	The concept is feasible, as long as we have sufficient automation
5	The concept works, if the automation works. Overall, the concept is acceptable as an idea. It requires high trust in automation. Responsibility issues due to possible technical failures (e.g., link loss)
6	The concept worked quite well and it is a conservative one. But there are technological challenges on how the connection between the ground station and the aircraft will be established and safe.
7	The concept is acceptable, it is already being used in drones and this can happen in commercial aviation as well. However, there are issues, like security and datalink. Responsibility: comfortable with being the PIC without having manual control on the aircraft.

Subj N	Roles, responsibility, and task allocation – More help needed
1	Vectoring scenario not acceptable. In this case, an extra person on the ground should support the GSO: one changing the settings and controlling the aircraft, the other monitoring and communicating with ATC
2	It depends on the advancement in technology. Handling other possible failures can be very difficult from the ground “it could become difficult for the GSP performing the emergency descent, performing the engine damage and the checklists, taking care of the passengers etc”. Instead, for “normal” failures, a GSO is sufficient

2	Not necessary having AOCC getting more info on the health status of the OBP
3	No extra-support needed
4	The console does not have enough information for the GSO to decide for a missed approach. But if the console had similar resources to today's cockpit, it would be enough.
5	Some airlines have control centres (AOCC) that can assist the pilot when requested. This can be also extended to the GSO.
5	In the radar vectoring scenario, the GSO just waits for the advanced landing system to engage again. This can be a problem, as the subject had the feeling that he/she did not have the tools to control the aircraft in this case.
6	The GSO had enough information, technical status, all the relevant information to call a missed approach. But it is more stressful, because you have to trust only on systems (as in a CAT 3 approach today).
7	AOCC could be useful depending on the scenario. It could have no impact at all to critical impact, depending on the situation.

Subj N	Roles, responsibility, and task allocation – Training needed
1	Specific training needed for GSOs. The GSO does not need to fly manually, but an operational experience would be required to deal with procedures, systems, communication, etc.
2	Not necessary to be a captain, but operational experience needed. "Level of experience is something to explore… I guess you have to find the point where it is acceptable or not acceptable (being a GSO)". Suggestion: test subjects with different levels of experience.
3	Operational experience needed. Suggestion: alternate pilot flying and GSO role, to keep handling skills, mental flexibility and motivation.
4	At the beginning, the GSO must be a trained pilot to have operational understanding of the situation. Maybe after the stabilisation of the concept, the GSO could have less training.
5	The GSO must have been in a cockpit and needs to be a pilot. But not so much experience is needed, similar to a First Officer is enough.
6	-
7	GSO with the same training and procedures of the on-board pilot would be the safest approach. "Basically you turn the SPO into a multi-crew operation and multi-crew operations work naturally better if the crew is trained in the same way with the same procedures". But maybe there is the option to have people without full pilot training.

Subj N	Operating procedures - Acceptability
1	Handover procedure acceptable (but meaning not fully understood)
1	Incapacitation mode necessary to handle incapacitation. Automation does most of the work, with some level of control from GSO

2	"It was straightforward…it was very well designed, taking care of the aircraft, selecting the pilot incapacitation emergency mode, declaring pilot incapacitation with ATC… It was beautifully done; I cannot see any problem with the operating procedures"
3	Procedures were not clear enough (especially GSO-OBP communication procedures)
4	Procedures were fine.
5	Incapacitation procedure was easy because there was a red light and everyone knew what to do.
5	More clear rules of engagement could help the GSO to take over in case of failure of the pilot incapacitation detection system and OBP not answering.
6	Procedures were fine.
7	The procedure was very rushed. Depending on the scenario, the subject wouldn't go straight to the approach, the GSO would first get SA about the situation and understand what is happening.
7	Some simplified procedures could help such as DODAR or FORDEC.

Subj N	Team and communication – communication and coordination between actors (GSO-OBP and GSO-ATCO)
1	Communication flow GSO-ATC was good.
1	ATC expected to know the incapacitation procedure and the behaviour of the aircraft once incapacitation mode is selected and expected to clear the airspace. Not much interaction with GSO is expected
1	GSO and ATCOs need common procedures to avoid flying into turbulence or over cities
1	Communication GSO-OBP: preferable than console info only, it enhances SA. Dedicated audio communication is more efficient than text.
1	Communication GSO-OBP: constant communication helps with incapacitation detection and many other aspects.
1	Change frequency: to be avoided
2	The level of interaction GSO-ATC was good
2	ATCOs are expected to know the emergency procedure, and they are not expected to be too proactive. GSOs need to communicate their intentions (e.g., stop on the runway or taxi out and shut out the engines). ATCOs can recommend doing something, for example if the aircraft has some problems with the engine, they would suggest to stop on the runway [...]. So, they can be proactive in the sense of asking me if I want to stop on the runway or not, but I don't think that they have to interfere too much because the risk is that they can give pressure to the pilot
2	Change frequency: the frequency could be blocked, reducing WL. Nevertheless, changing freq. didn't make a huge difference.
2	Communication GSO-OBP: "I like communication to be short, precise, and understandable. I would cut-down on unnecessary checks or confirmations… but I think that this is necessary because the GSO is not in the flight deck"
2	"Active GSO": interaction between OBP and GSO is needed. They have to work as a crew. "I would prefer to have a confirmation and a conversation with someone instead of sitting and just calling

	for ATC and calling checklists by myself… I guess that should be an interaction. I think it is better to have an interaction, but I'm not saying that if there isn't there is the end of aviation".
3	"Active GSO": interaction between OBP and GSO needed. Reading the checklists and communicating with ATC keeps GSO in the loop.
3	Communication GSO-ATC: ATCOs need to apply standard procedures in case of incapacitation (an ATCO asking too much increases GSO WL and can possibly disturb landing). If incapacitation happens in other moments, ATC can help with decisions.
3	Communication GSO-OBP: procedures on communication need to be more precise
3	Change frequency: the frequency could be blocked, reducing WL.
4	"Active GSO": Even having some tasks, the GSO does not have much to do in nominal cases. If the OBP does everything would be more efficient, and the GSO would just monitor the OBP.
4	If OBP and GSO have the same controls and activate the same command, it would be a problem.
4	Communication GSO-ATC: communication is the lowest priority. In an emergency, the GSO does not really need to communicate with ATC. The ATC will clear the traffic anyway.
5	"Active GSO": would be nice, but is not critical. In general, it is not necessary to have this regular contact, only in case of emergency. But a permanent audio connection with OBP is important.
5	Confusion about who is talking to the GSO: ATC or OBP. Suggestion: include an indication about that.
5	Communication GSO-ATCO: the conversation was a bit too much, normally there are less waypoints to call.
5	Change frequency: not necessary between approach and tower, in case of pilot incapacitation. It can reduce workload.
6	Communication GSO-OBP: we need to define clear rules on how the GSO and the OBP will interact and who does what (new CRM based on today's CRM).
6	Communication GSO-OBP: there may have more callouts than in today's operation, as both pilots are in different locations. It will increase redundancy and keep them in the loop. The GSO can just check, instead of read-back everything (only readback for flap or landing gear, because today it is done by pilot monitoring).
6	Communication GSO-OBP: we have to find an intermediate option between fully passive and fully active role to GSO. A more passive role could be acceptable, but it could affect the readiness to assume after incapacitation.
6	If the GSO participated only in emergency cases, we have two main problems: pilot incapacitation detection can fail and the level of readiness for the GSP to takeover can be very low.
7	"Active GSO": safest operation. Having access to the pilot on-board is a requirement, with a good communication.
7	Coordination GSO-OBP was fine, was like multi-crew working

Subj N	Team and communication – expectations toward the automation (incapacitation mode and advanced landing system)

1	The automation is expected to land the aircraft even without receiving any inputs from the ground. It avoids human errors, datalink failures, etc.
1	A more advanced system could analyse, generate options, and propose the best ones to the pilot. The pilot (GSO) is the one taking the decision.
2	“Prepare the aircraft for the approach. Selection of LFS, flaps, speed reduction, it would be nice also an automatic selection of the lowest altitude, so that the a/c is already in landing mode [...] Secting the lower altitude, lowering the speed, etc… increase the GSO Workload and decrease Situational Awareness. When pushing the button, all these things will be managed by the aircraft. But on the other hand, the GSO has to check that all these things done by the aircraft are doing right, otherwise it would be dangerous”.
3	Automation should slow down the aircraft giving time to the GSO to understand the situation, revert to approach mode (?). Once incapacitation is detected, the system should revert to the highest possible level of automation
3	Automation needs to be transparent for GSO
4	The automation should have the ability to do a go around if the pilot does not react on time.
4	We already have advanced automation that commands landing gear, flaps and that does automatic landing.
4	The incapacitation mode is expected to enable commands from ground that were not engaged before. But automation would not do anything different.
5	The subject liked the advanced landing system. The automatic actuation of landing gear and flaps is a great improvement from today’s automation.
5	It needs a lot of trust in automation to control the aircraft just by high level commands from ground.
5	The voice control is really tricky, it is not the best option. Commands using buttons are more robust and preferable.
6	When pressing the incapacitation button, it is expected that nothing directly changes, but the GSO knows he/she is in charge and can command the aircraft.
6	The advanced landing system could be engaged just before intercept localizer (in radar vectoring scenario). But the GSO can fly headings without this advanced landing system.
7	Assume the responsibility of being PIC is not a problem. Nowadays, we already have a high level of automation. “We tell the computer to do stuff and the computer does stuff.”
7	The incapacitation mode is expected to disable the on-board controls and enable the GSO to take control of the aircraft, treating it as an UAV. However, the on-board pilot has always the final decision, being able to disconnect all automation and fly the aircraft by hand.
7	Autoland systems already exist and manufacturers could improve it to become an advanced landing system, with automatic reconfiguration of the aircraft and other required functions.

Subj N	SA – additional info needed
1	More info needed on OBP and aircraft status (why is incapacitation happening?). A camera inside the cockpit would help.

1	A camera giving pilot view would help.
1	One screen is very limited. Weather radar display and approach charts would be very helpful.
1	Holding procedure to build more SA not necessary, since the GSO has limited control and the automation is doing most of the work. Priority to land ASAP.
2	More info needed on OBP medical conditions + info on gender, age of OBP etc in order to transmit them to ATC
2	It would be nice to have basically OBP information (engine, fuel parameters, navigation display, PFD, etc.).
2	A camera inside the cockpit would be useful but not strictly necessary. A camera outside is not the most important, as IMC conditions are already without the image from outside.
3	A camera giving outside view could be useful, or a head up display.
3	HMI: More info displayed on the console (flight plan, alternate airports, engine status, weather radar, airspeed indicator, Flight Mode Annunciator)
3	HMI: incapacitation alert visual + acoustic
3	HMI: info on console is coming and going. Show information with different colours: white (armed), green (active), and keep them
4	Ground Station resources should be basically what the pilot has in a real cockpit.
4	Camera inside the cockpit would be useful to have another way to check incapacitation. But an external camera is not very useful, as today we do CAT 3 without seeing anything anyway.
5	It is always good to have the health status of the incapacitated pilot. Health support can be done on-board by flight assistance.
5	Cameras are an added value. Camera for the GSO to see the OBP would be nice. An outside camera is also useful. A camera in the GS would be also beneficial.
5	HMI: include an indication of who is talking with the GSO: ATC or OBP. It can reduce confusions.
6	It would be helpful to have a second display with background information (fuel, engine, systems, etc.). But the main display is enough, we should not include much more information there.
6	A camera inside the cockpit would be useful to detect incapacitation, not to monitor what the on-board pilot is doing.
6	A camera giving an outside view is always useful, but not required (CAT3 and IFR are done today without an external view). As the automation is doing the aviate, the PFD is enough and there are other things that are more important.
6	HMI: we could include an indication of who is talking in the GSO. There is a ring to communicate with the AOC in SELCAL that can go to the GSO as well, if we have a passive GSO.
6	HMI: incapacitation alert and incapacitation button being close or being the same button
6	HMI: info on console is coming and going. It would be beneficial to see “what’s next” (e.g., next: descent checklist).
7	A camera is not essential, but it can help to detect incapacitation.

7	Complete PFD and ND could be very useful. Status of the systems are also required if we have failure scenarios.
7	HMI: make things blink when they change or include a different square around the things that are changing would help situational awareness.

Subj N	WL and SA (and differences between scenarios)
1	WL is too high for just one GSO in the vectoring scenario (change settings, communicate with ATC, do the checklists), resulting in lower SA. Risk for safety. Suggestion to minimize WL: go for automatic approach (STAR procedure).
1	A second pilot on ground would be required if we have incapacitation with radar vectoring and other difficulties.
2	"You can have a very challenging scenario where the SA needs to be at a very high level, but these scenarios were quite straightforward, I think that all the pilots should be able to make these scenarios". Suggestion for a different scenario to test SA: departure from multi runway airport and bad weather conditions.
2	WL in the nominal scenario was standard. WL level in case 2 and 3 was similar
3	WL was higher in the vectoring scenario (not enough time to think; risk of missing/forgetting). Vectoring should be avoided. ATC should send the GSO to the closest waypoint.
4	SA was good, there was not much for the GSO to do, just social interaction.
4	WL was ok. Radar vectoring scenario had a higher workload, but it was not a problem. We do radar vectoring all the time. This is not a limitation of SPO.
5	Vectoring should be avoided. Preferable to return to a waypoint in order to have the Advanced Landing System back and proceed with automatic landing.
6	WL level in case 2 and 3 was quite the same.
6	Radar vectoring with incapacitation is acceptable, if the technology is available.
7	WL level in case 2 and 3 was different, but it is not significant.

Subj N	Safety – other hazards and possible mitigation solutions
1	In case of **link loss** with aircraft, autonomous systems should be available to continue the flight to a safe landing.
1	For **link between ATC and GSP** incapacitation button should show ATC the aircraft capabilities/systems available to increase safety. More active ATC.
1	**Technical failures**. text
1	Adverse **weather** and other external hazards such as blocked runways should be avoided in incapacitation scenarios. Airport selection system should have criteria to avoid such safety risks.
1	
2	Voice recognition in the console could be a threat. Different accents might be hard to differentiate, especially in a situation with technical failures where stress can affect how each

	person speaks (clarity etc.). **NOT RELEVANT for safety assessment, voice control over console not part of SAFELAND concept. This info can be transferred in the following table (miscellanea)**
2	**Latency** issue: 2 secs are not a big deal. Needs to be tested in RTS. **Multiple link connections** between GSP and aircraft would create redundancy in case of failure. Sensors on the pilot to be able to automatically activate incapacitation mode in case of link failure. Autonomous aircraft systems would be required.
2	If a/c not stable, GSO must **go around** (unless the a/c is facing other problems such as other failures or low fuel)
2	In case of **multiple failures**, several GSP's would be desirable as dealing with these remotely could be a threat for a single GSP.
2	Threat of **high energy approach due to workload** so expectation would be that the console and advanced landing system descends to the minimum altitude and reduces speed automatically.
3	Threat of **missing the pilot incapacitation signal**. Desired aural alert along with the flashing red light to mitigate the threat. Would make it easier to identify the problem. Automatic Squawk should be set by aircraft when incapacitation is detected.
3	**Adverse weather** conditions would be difficult to deal with as GSP so expectation would be ATC assistance to mitigate such situations.
3	Threats of **technical failure** such as pressurization causing emergency descent, engine failures or more severe failures such as dual engine failure require a good level of automation and information displayed to GSP.
3	**Link failure** requires a default mode that autonomously follows the flight plan when loss of connection is detected.
4	On ground threats such as **runway incursions** could be mitigated by the GSP having access to a ground movement feed from ATC. External viewing cameras on the aircraft won't always be helpful as it depends on atmospheric conditions.
4	Management of **technical failures** depends on the amount of ground controls available. The GSP needs software to act as physical hardware such as fire switches, rudder pedals and so on.
4	**Datalink failure** mitigation requires automation on board to proceed on previous clearance autonomously. Stability of the link is essential for GSP to feel comfortable being responsible for the operation once an incapacitation occurs. Cybersecurity is a massive threat for hostile takeover. GSP interference without pilot incapacitation is a threat.
4	For situational awareness and to avoid initiating the pilot incapacitation procedure in case of communication failure, the GSP should have access to a video feed that starts once an incapacitation is detected. To be used as a secondary measure to confirm the pilot is incapacitated and in what state he/she is.
5	Biggest threat in the operation is due to **link failure and cyber security** of the link between the aircraft and the GSP. High levels of automation and trust in the software required to be able to have a safe operation.

5	**Communication failures between ATC and GSP** on the other hand are easily resolved by phone calls or text messages similar to CPDLC.
5	**Technical malfunctions** are not interesting to look at as the improbability of having a technical issue on the same day that a pilot incapacitation occurs is very low.
5	Automation required for a smooth go around procedure where the aircraft can regain the STAR routing and execute a second approach.
5	A link to the cabin crew or anyone on board that can help in case of incapacitation would be very useful to mitigate risks associated with the incapacitation such as securing the pilot away from the physical controls. Also cameras on board and with the GSP would help the trust factor between the two and make the operation more reliable.
6	**Main risks: link loss and cybersecurity issues**. In order for the concept to work safely, the connection between the aircraft and GS must be reliable and secure. In case of link loss, automation should be available to continue the flight to a safe landing. In this case, ATC must be warned that the aircraft is proceeding without any controls from the ground, so no possibility to make any changes.
6	Going around is a possibility if the GSO is not able to get all necessary information to continue the approach safely (?), or in case of other issues (e.g., runway incursion).
6	Risk of failure in the incapacitation detection system.
7	**Cyber security** was mentioned as the main concern for the operation. The failure of the aircraft-GSP link is a big safety risk. Autonomous aircraft possibilities need to be available to land the aircraft along with degraded modes in case of failures.
7	The training of the GSP should be as a pilot to make the concept as safe as possible.
7	Awareness of the situation when located on the ground is a big risk. **Weather radar** required and possibly more advanced radars to be aware of birds and other atmospheric risks.
7	Non monitored failures also pose a big risk and need to be easily assessed by the GSP. An example is the autoland capability which may be unannunciated. The general criteria for the systems the GSP needs has to be visible via some lights or indications of some kind.
7	Ultimate responsibility lies with the on board pilot and would need some kind of override button to take control if necessary. This poses a risk to security in case of partial incapacitation.

Subj N	Miscellanea
1	Voice control over the console is perceived as acceptable.
1	The subject preferred using “Mayday” over “pan-pan”
1	HMI: The subject confused the indications of landing gear and landing lights. Suggestion: separate them

1	"I don't think that the GSO can call a go around between FL100 and 0 feet, because you don't have the information to do that." As the reasons for calling a go around (aviate aspects) are not controlled by a GSO.
2	Voice control over the console can lead to some trouble (e.g., different accents)
2	The subject preferred using "pan-pan"": situation is urgent but not serious aircraft issue
2	It would be nice to do the LFS with a cadet (pilot just after the fly school).
2	The subject offered to write down challenging scenarios examples for future simulations.
3	The subject preferred using "Mayday" over "pan-pan"
3	Voice control over the console considered not acceptable (takes time, can overlap with ATC com)
4	It should take around 22 seconds for the GSO becoming PIC after incapacitation (20s trying to contact the OBP twice and 2s to take command).
4	Partial incapacitation is an issue. A cockpit disconnect button would be needed, but then anyone on ground could control the aircraft.
5	Website of CEFA aviation: the setup and videos could be useful to get some ideas and improve the simulations.
5	The pilot incapacitation is a "Mayday" case.
5	Manual control over the console preferable than voice control
5	Possibility to unlock the cockpit door from ground and get help from non-flying crew members/passengers
6	**HMI**: The subject had trouble with the location of the incapacitation emergency mode button. Suggestion: place it next to the incapacitation alert or the alert can be the button itself.
6	It will be hard to find **new frequencies** in Europe to provide the open channel between the GSO and the OBP.