Model of Flight Tasks

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SAFELAND

SAFE LANDING THROUGH ENHANCED GROUND SUPPORT

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Abstract (Executive Summary)

To support the SAFELAND Concept development (Task 1.2), the project generated some models of flight tasks, as they are performed in a two, single, or incapacitated pilot configuration.

Based on a conducted Cognitive Work Analysis this document provides, on the one hand, an overview of the aircraft functions and task that are required to be performed by the various actors involved in a flight.

On the other hand, this document illustrates the high-level interactions between these actors for specific aircraft function in dedicated flight phases.

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List of acronyms

Term	Definition
AOCC	Airline Operations Control Center
AP	Auto Pilot
ATC	Air Traffic Control
ATM	Air Traffic Management
CAT	Contextual Activity Template
ConOps	Concept of Operations
ConTA	Control Task Analysis
CWA	Cognitive Work Analysis
E-OCVM	European Operational Concept Validation Methodology
GCSS	Ground Control Support System
GSO	Ground Station Operator
HF	Human Factors

HURID	Human Risk Informed Design
LNAV	Lateral navigation
OESD	Operational Event Sequence Diagrams
PF	Pilot Flying
PM	Pilot Monitoring
REACTOR	Reducing Workload through Efficient Technology and Procedures
RPAS	Remotely Piloted Aircraft System
SJU	SESAR Joint Undertaking
SOCA	Social Organisation and Cooperation Analysis
SPO	Single Pilot Operations
TCAS	Traffic Alert and Collision Avoidance System
TRL	Technology Readiness Level
VNAV	Vertical navigation
WCA	Work Competencies Analysis
WDA	Work Domain Analysis

Table 1: List of Acronyms

1 Introduction

1.1 Purpose and scope of this document

The purpose of deliverable D1.1 *Model of Flight Tasks* is to describe a flight task model for different aircraft configurations (dual piloted, single piloted and remotely piloted aircraft) of an aircraft certified according to the certification standard for large aeroplanes (CS-25; EASA, 2003).

The model incorporates function allocations between actors involved (e.g. AOCC, ATC, remote-single pilot, cockpit crew) during the duration of a commercial flight from one airport to another in controlled airspace.

This Flight Task Model shall describe the functions needed to be conducted for a safe and efficient aircraft operation in detail. Especially, the roles and responsibilities of the various actors with regard to specific functions and tasks will be examined and ultimately defined by taking different aircraft configurations into account.

The main objective of this document is to define current distribution of functions and tasks for the involved actors of aircraft operations based on Cognitive Work Analysis (CWA) and their interaction.

The work summarised in this document will be used, in Task 1.2, to support the design of the SAFELAND operational concept. The models generated by Task 1.1 are fundamental to understand the impact of the possible solutions to the single pilot incapacitation problem on the tasks and role allocation, so to build an operational concept that maintains the same levels of safety and to keep track of how the roles and tasks distribution would change with the final concept.

1.2 Structure of the document

This document is divided in total into five chapters with multiple subsections.

- Chapter 1 describes the purpose as well as the scope of this deliverable. In addition, Chapter 1 also highlights the collaboration of SAFELAND with other H2020 projects for the aim of writing this deliverable.
- Chapter 0 details the methodology used, in order to define a flight task model for the project. Based on Cognitive Work Analysis (CWA) the SAFELAND Flight Task Model will be developed.
- Chapter 3 elaborates the Flight Task Model (based on CWA) for all actors involved in detail where three different aircraft configurations were taken into account.
- Chapter 4 illustrates the interactions between the involved actors (e.g. ATC, AOCC, remote-single pilot, etc.) for specific aircraft functions and tasks during dedicated flight phases
- Chapter 5 concludes the results made in this document, and discusses limiting factors for each aircraft configuration. A short outlook to deliverables D1.2 SAFELAND Concept is also given in this chapter.

- Finally, chapter 6 lists the references that were used within this deliverable.

1.3 Collaboration with other projects

The SAFELAND consortium is exploring synergies with other H2020 projects continuously. This subsection details the first results made to establish collaborations between SAFELAND and **two other relevant projects from similar work domains within the H2020 framework** (for the complete list of projects, please refer to D5.1 Project Management Plan).

1.3.1 SAFEMODE

The SAFELAND consortium was able to establish a first collaboration with the SAFEMODE project that focus on the creation of the **HURID framework – Human Risk Informed Design**. HURID is aimed at support designers in the creation of new systems or systems of systems solutions, namely with increasing automation and potentially autonomy.

SAFELAND will benefit from SAFEMODE developments on Human Factors (HF) tools and methodologies to support its concept definition. On the other hand, SAFEMODE will obtain from SAFELAND participants feedback on the usage of HURID framework tools, which it can feed into its improvement before the end of the project.

Meetings	Date	Main Actions/Decisions
#1 (online)	31/07/20	Brief introduction to the focus, scope and activities of SAFEMODE project. A set of possible SAFEMODE results was mapped to support SAFELAND (e.g. Operational Procedures).
#2 (online)	19/08/20	The development of the flight task model and the evaluation workshop were considered the main points of collaboration the two projects. SAFEMODE has already developed several operational descriptions of scenarios applicable for developing a flight task model for the take-off and initial climb phase. Embraer agreed to provide to adapt the task model vision for the approach and landing phase to be used in SAFELAND. It will then be merged with work on Cognitive Work Analysis done by DLR
#3 (online)	27/08/20	Presentation of a detailed task model for the landing sequence beginning from the top of descent. These graphics will be added to D1.1 (with some adaptions). DLR will merge the function distribution proposed by EMB with SOCA in D1.1. The identified sub-functions (e.g. attitude of aircraft, airspeed) shall be allocated to generalized functions (e.g. aviate, navigate) whenever possible. This allocation will be agreed on consortium level by SAFELAND.

Table 2: Collaboration meetings between SAFELAND and SAFEMODE

1.3.2 REACTOR

The H2020 Clean Sky 2 REACTOR (Reducing Workload through Efficient Technology and Procedures) project is aiming at reducing pilots' workload by developing novel technologies and procedures, especially for demanding flight phases (e.g. Take-Off, Landing). Hereby it is leading the way towards Single Pilot Operations (SPO) for commercial airliners and ultimately to remotely piloted aircraft systems (RPAS), as it examines pilots' workload reduction by proposed technologies for dual piloted aircraft.

The collaboration between SAFELAND and REACTOR is focused on transfer of publicly accessible project findings, its dissemination as well as exploitation activities. SAFELAND will benefit from the technology development within REACTOR, as for instance a **Ground Control Support System** (GCSS) for supervising and guiding remotely piloted aircraft is proposed by the project. In addition, **procedures for reducing pilots´ workload** might find their way into the SAFELAND concept, which will be described in deliverable D1.2. REACTOR however, will capitalize on the final SAFELAND concept as one approach for SPO in the commercial aviation domain.

1.4 Project scope and assumptions made in D1.1

SAFELAND is considered as a Horizon 2020 SESAR EXPLORATORY RESEARCH project. In accordance with the SESAR maturity criteria (SJU, 2018) EXPLORATORY RESEARCH projects are not expected to reach maturity levels beyond Technology Readiness Level (TRL) 2 (Basic Technology Research), which mostly corresponds to V1 level of maturity on the E-OCVM (Eurocontrol, 2010). In line with the E-OCVM description of typical V1 maturity level, **SAFELAND will primarily focus on defining the initial operational concept, including the exploration of different alternatives and the identification of show-stoppers.**

At the V0 and V1 maturity levels there is often no clear and unambiguous view of how to implement the concept. Therefore, building high fidelity prototypes is not the primarily scope of SAFELAND. However, real time simulations and prototyping sessions are to be conducted in a simplified environment with at least a preliminary version of support tools and automation. Data collected will then be used, analysed and discussed during expert groups (e.g. within the Advisory Board) and workshops in order to develop the SAFELAND concept and plan future research activities (SJU, 2020).

Given the maturity level of SAFELAND and its interdependence with other projects (e.g., those covering the airside aspects of SPO as for instance Clean Sky 2 LPA DISCO project (Clean Sky 2 Joint Undertaking, 2018), the consortium realized that the research taken place would benefit from a List of Assumptions. These are being collected in a living document to be maintained throughout the duration of the project. In particular, to support the work in this deliverable, key assumptions were made.

The first assumption refers to the **data link connection**. It was assumed that a reliable and sufficient C2 (command & control) data link connection (incl. radio communication) between air and ground is given at any time.

Further, this deliverable assumes the presence of a **ground station to monitor pilot and system health** during all phases of flight during single pilot operations without the possibility of actively intervening. The subsequent deliverables of WP1 will analyse how a potential ground station could intervene in case of a pilot incapacitation.

Finally, it is assumed that future SPO aircraft is equipped with more **sophisticated automation** than a conventional CS-25 aircraft with an operating crew size of two.

2 Methodology

This chapter describes the CWA framework that was applied to create a descriptive model of the flight tasks needed to be executed in dual, single and remote single pilot operations. Further, the method to describe the interactions between the involved actors is described in 2.2.

2.1 Cognitive Work Analysis (CWA)

In the human factors' literature several different work analysis techniques can be found, which have evolved from either of two fundamentally different approaches of analysing work. One approach focuses on identifying the tasks and actions the operator is required to perform when interacting with a system in order to achieve a certain system goal (Kirwan & Ainsworth, 1992). Such techniques mostly follow the so-called instruction-based approach to task analysis (Vicente, 1999). Instruction-based approaches describe the work system in great detail and make strong assumptions about it. As such, the work domain for which the system is being created has to be well known in order to create design requirements. Another approach, namely the ecological approach to work analysis focuses on the constraints and capabilities that a work domain imposes on the work (Vicente, 1999 and Miller & Vicente, 2001). The analysis is device-independent and independent of worker competencies. Techniques following this approach are so called constraint-based approaches and an example is the Cognitive Work Analysis (CWA; Rasmussen, Pejtersen & Goodstein, 1994; Vicente, 1999). CWA is a framework, developed to model how work could progress within complex sociotechnical work systems. The term sociotechnical work system refers to a system within which humans and technical elements work together to achieve a common purpose (Jenkins, 2012).

In the case of future systems, it is difficult to define specific tasks that have to be executed since these systems cannot be observed. Furthermore, workers often develop new ways of working while they gain experience with the new systems (Elix & Naikar, 2008). CWA offers a solution for the problem, as **it models how work could be done instead of how it should be done**. Thus, as opposed to designing systems based on predefined tasks, basing the design on constraints imposed by operational conditions and system resources leaves a space of possibilities for actions the operators can take (Jenkins, 2012). Since actions are highly dependent on the situation, this space of possibilities permits the system to better account for unanticipated situations than systems that were designed based on predefined tasks (Vicente, 1999). Further, within complex sociotechnical systems, there usually is not always the one right way to accomplish a certain purpose but workers can adopt different strategies of how to proceed, depending on the specific situation. Through a CWA the workspace within which workers can operate is determined and information as well as human-machine interface requirements can be derived. CWA consists of five phases (cf. Table 3), namely (1) Work Domain Analysis (WDA), (2) Control Task Analysis (ConTA), (3) Social Organisation and Cooperation Analysis (SOCA), (4) Strategies Analysis (STA) and (5) Worker Competencies Analysis (WCA).

No	Phase	Purpose	Methods applied in SAFLAND
1	Work Domain Analysis (WDA)	Representation of the work system independent of specific events, tasks, activities and actions.	Abstraction Hierarchy (Rasmussen, Pejtersen, & Goodstein, 1994)
2	Control Task Analysis (ConTA)	Identification of activities necessary to achieve the purposes and functions of a work system by decomposing the system activities into control tasks for defined situations and work functions.	Contextual-activity template (CAT; Naikar, Moylan, & Pearce, 2006)
3	Social Organization and Cooperation Analysis (SOCA)	Distribution of identified tasks onto participating agents (e.g. human and automation).	SOCA-CAT
4	Strategies Analysis (STA)	Identification of possible strategies for executing identified tasks.	-
5	Worker Competencies Analysis (WCA)	Identification of competencies workers must possess when interacting with the system.	-

Table 3: Phases of Cognitive Work Analysis

SAFELAND will focus on the WDA, ConTA and the SOCA in order to derive a descriptive model of the flight tasks for current dual-pilot operations. Further, the methods will be applied to derive and compare different options for function allocation for single-on-board and single-remote pilot operations. Since the aim is to specifically investigate different options of function allocation for the different aircraft configurations (i.e. dual, single and single-remote pilot operations), the results of the STA and WCA would not provide any significant benefit for the analysis. Therefore, the WCA will not be considered in SAFELAND. However, the STA may provide useful results during the final SAFELAND concept with regard to different strategies for taking over control and remotely controlling an aircraft after a pilot incapacitation has occurred.

2.1.1 Work Domain Analysis (WDA)

In order to analyze a work domain, it is important to get an understanding about the possible scope of action that is limited by the physical boundaries and constraints that are present in the work system. One method for this purpose is the development of an abstraction hierarchy. An **abstraction-decomposition hierarchy** visualizes the functions of a work system on five levels of abstraction, ranging from functional purposes to physical forms (cf. Table 4). These functions in turn define the scope of action, i.e. the constraints of the work system (for further details please refer to Rasmussen, Pejtersen, & Goodstein, 1994 or Vicente, 1999). Further, the abstraction shows how functions relate to each other by connecting the functions that share a means-end relation with each other. This means that the level above an abstraction level describes why the function in this abstraction level is being executed and the level below describes how it is executed.

Abstraction Level	Description
Functional purpose	Reasons and purposes why the work system exists
Abstract functions	Criteria by which the achievement of purposes can be judged
Generalized functions	Functions that are necessary to achieve the purpose of the work system
Physical functions	Processes necessary to carry out the purpose related functions
Physical form	The physical constraints of the work system

Table 4: Description of levels of the abstraction hierarchy

2.1.2 Control Task Analysis (ConTA)

Activity within a work system can be investigated by further analyzing the functions that were included in the abstraction hierarchy in terms of their respective contribution in specific work situations. For this purpose, the functions are mapped onto a so-called contextual activity template (CAT; Naikar, Moylan & Pearce, 2006). A CAT is a matrix with the horizontal axis visualizing situations and the vertical axis visualizing functions. Solid bars indicate situations in which the function should be active in order to fulfill its purpose. Dotted boxes indicate that the respective function can be active, as opposed to must be active.

Situation Function	Situation A	Situation B	Situation C
Function 1	|—————| (dashed box)		
Function 2		|—————————————| (dashed box, spanning Situation B and C)	
Function 3		|—————| (dashed box)	

Table 5: Illustration of Control Task Analysis

2.1.3 Social Organization and Cooperation Analysis (SOCA)

Analysis of **function allocation between different actors** (e.g. pilot flying (PF), pilot monitoring (PM) or automation) can be accomplished by conducting a social organization and cooperation analysis (SOCA, Vicente, 1999). One way to visualize the results of the analysis is to fill the bars in the CAT with different colors, each representing a different actor. A CAT, combined with a SOCA is referred to as SOCA-CAT (e.g. Stanton, Harris & Starr, 2016). In order to visualize different function allocation concepts in a work system, such as an aircraft flying in controlled airspace, the SOCA-CAT can be use. In consequence, D1.1 details the results of CWA in order to model flight tasks for different aircraft configurations, namely dual piloted aircraft, single piloted aircraft and remotely piloted aircraft (cf. chapter 3).

2.2 Interaction modelling

In order to describe the **interactions between the actors involved** in the execution of the individual functions, a method was chosen that is closely related to the so-called Operational Event Sequence Diagrams (OESD; Harris, Stanton & Starr, 2015). Compared to the OESDs, which describe the interactions in great detail, for the purpose of the current analysis an approach was chosen that describes the interactions at a higher level of abstraction. The reason for this choice was that a high-level description of the interactions was regarded as providing enough information for the purpose of this deliverable. The interactions will be further refined within the scope of deriving the initial SAFELAND concept in D1.2.

Figure 1 illustrated the chosen method for describing the interactions between involved actors when executing individual functions. The diagram consists of columns, each of which represents a different actor (e.g. pilot flying or the automation). Mandatory interactions are represented as solid black lines. A dotted black line represents interactions that do not necessarily occur. The automation for example notifies the pilots if the aircraft's sink rate is too high. This interaction is not mandatory. However, it will occur if the sink rate is out of the normal range and poses a safety risk. A dotted red line represents interactions that require new technology or automation that is currently not available for commercial aircraft.

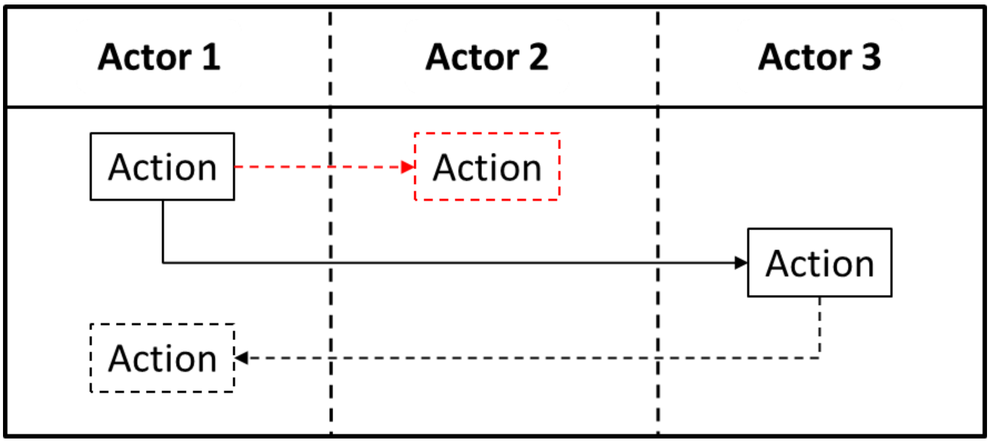


Figure 1. Method for describing the interactions between involved actors during the execution of a function.

3 Flight Task Modelling using CWA

This chapter presents and describes the developed flight task models for dual, single and remote-single pilot operations as well as different alternatives of function allocations for the situation of a single pilot incapacitation in cruise using CWA. The models were developed through an iterative review process (cf. Figure 2). The flight task and function allocation models for on-board single pilot incapacitations will be further evaluated and refined in D1.2 in order to derive the initial SAFELAND ConOps. For this purpose, an evaluation workshop is planned.

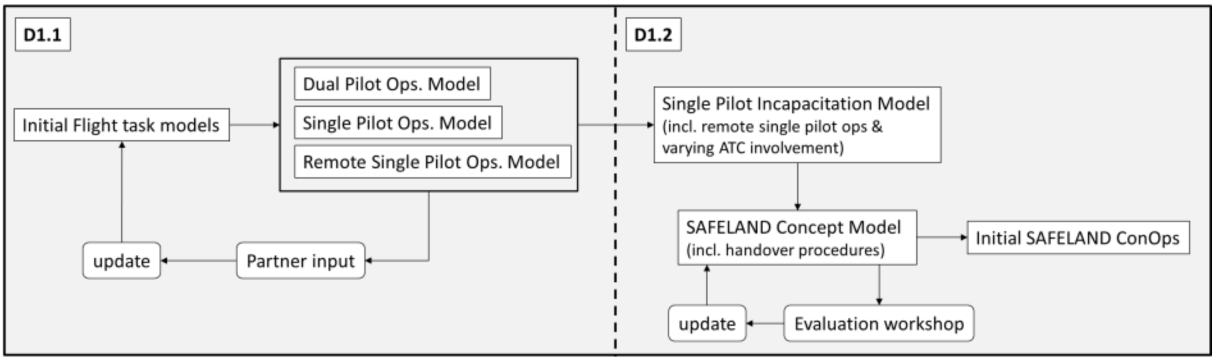


Figure 2. Iterative review process for flight task modelling and deriving the initial SAFELAND ConOps.

3.1 Work Domain Analysis - The Abstraction Hierarchy

As described in subsection 2.1, the first step of CWA is to build a descriptive and exhaustive model of the work system using the abstraction hierarchy. After the abstraction hierarchy is built, the different aircraft control configurations (i.e. dual, single and single-remote pilot operations configurations) with regard to activity allocation can be explored. Since the work system, i.e. the aircraft itself, does not change depending on the control configuration, one abstraction hierarchy was constructed that describes the work system of a CS-25 certified aircraft, such as an Airbus A320, flying in controlled airspace. Figure 3 depicts the constructed abstraction hierarchy.

The purposes of an aircraft flying in controlled airspace is to conduct a safe and efficient flight. Therefore, the functional purposes were labelled as “Safe flight in shared, controlled airspace” and “Efficient flight in shared, controlled airspace”. In order to achieve these two purposes, the abstract functions “Internal risk management”, “External risk management” and “Energy management” are necessary. Internal risk management refers to avoid and manage any risks that originate from inside the aircraft (e.g. flight envelope excursion or engine on fire); external risks on the other side refer to risks from the outside environment, such as traffic or terrain. To manage the energy and the two risk factors, it is necessary to aviate and navigate the aircraft (cf. generalized functions level in Figure 3). Further, traffic needs to be coordinated in order to prevent collisions and aircraft systems as well as the pilots need to be available and in a good condition that allows for executing the needed functions appropriately. The physical functions describe all the functions that need to be executed in order to aviate and navigate the aircraft (e.g. altitude, speed or LNAV and VNAV functions). Furthermore, communication with ATC and AOCC as well as the monitoring of system and pilot health is necessary to achieve effective coordination of aircraft and to ensure aircraft system and pilot availability. The physical forms level represents all the physical objects that are present in the work system, which in this case are e.g. the aircraft systems, airspaces, flight routes as well as terrain, weather and other aircraft.

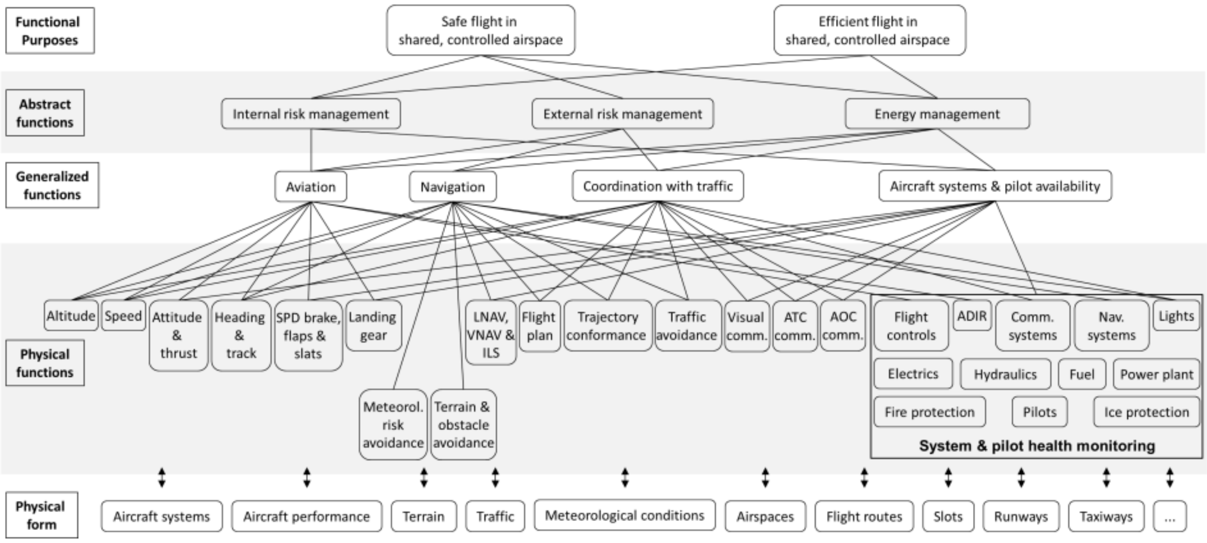


Figure 3. Abstraction hierarchy for a CS-25 aircraft flying in controlled airspace.

3.2 Control Task & Social Organisation and Cooperation Analysis

This subsection presents the developed SOCA-CATs for dual pilot, single pilot and single-remote pilot operations. For the purpose of constructing the SOCA-CATs, the physical functions from the abstraction hierarchy in Figure 3 were used. Further, all the situations that an aircraft flying from one airport to another in controlled airspace encounters during standard operating procedures were identified. For each situation and function it was analysed whether the respective function is active during the situation and who the agents are that take part in executing the particular function during the situation. The function "Landing gear" is for example active during the initial climb to acceleration altitude intermediate/ final approach phases of flight and is being executed by the pilot flying (who commands "gear up/ down") and the pilot monitoring (who actually executes the function by pulling the gear lever). FiguresFigure 4, Figure 5 and Figure 6 present the constructed SOCA-CATs.

3.2.1 SOCA-CAT for dual pilot operations

Figure 4 presents the current function allocation during dual pilot operations of a CS-25 certified aircraft flying from one airport to another in controlled airspace. The physical functions were allocated to the following actors: (1) Pilot flying, (2) Pilot monitoring, (3) Automation, (4) Optional automation, (5) Air traffic control and (6) Airline operation center. Optional automation is used in situation, in which the pilot can execute the function manually, if they wish to do so but may use the automation to take over. This is for example the case during the landing phase, during which the pilot flying can decide to fly the aircraft manually or let the automation perform an ILS approach. As such, the pilot can optionally use the automation if they wish or the situation requires it, for example during low visibility conditions.

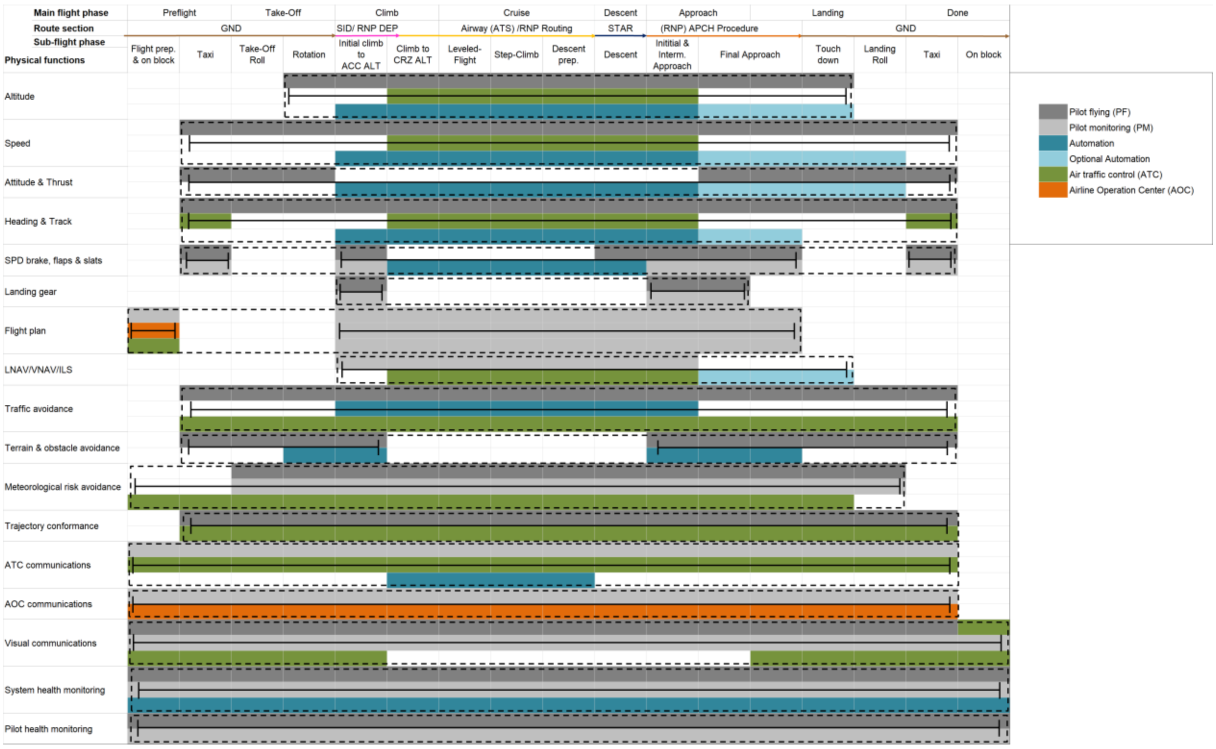


Figure 4. SOCA-CAT for dual pilot operations.

3.2.2 SOCA-CAT for single pilot operations

Figure 5 presents the developed SOCA-CAT for single pilot operations. For this use case, as anticipated in Paragraph 1.4, a central assumption was made, namely that the aircraft is equipped with more sophisticated automation than a conventional CS-25 aircraft with an operating crew size of two. Also, it was assumed that a ground stations constantly monitors both pilot and system health. These assumptions are based on numerous scientific publications arguing that in future single pilot operations, the degree of automation will most likely be higher than in current aircraft cockpits (e.g. Stanton, Harris & Starr, 2016) and that a ground station will need to be introduced to at least monitor the health of the single pilot but also to intervene and even take over control the aircraft in case a pilot incapacitation occurs (e.g. Lim, Bassien-Capsa, Ramasamy, Liu & Sabatini, 2017). Other publications propose to introduce a ground station that supports the single pilot on request during cruise when workload is normally relatively low and/or to have a ground station assisting the single pilot permanently during departure and approach flight phases with higher workload (Schmid & Korn, 2017). The current analysis assumes the presence of a ground station to (only) monitor pilot and system health during all phases of flight. Only in the event of a pilot incapacitation the ground station is assumed to take over control of the aircraft. Within the scope of D1.2, a concept for the procedures necessary for shifting the control authority from the single pilot to the ground station operator/ remote pilot will be derived.

In contrast to the function allocation analysis for dual pilot operation (cf. SOCA-CAT in Figure 4), considerably more functions are being allocated to the automation. This especially applies to the classic aviate functions, i.e. altitude, speed, attitude & thrust and heading. Further, the operation of speed brakes and high lift devices as well as the landing gear were allocated primarily to the automation with the single pilot having the option to intervene (labelled as "optional single pilot" in

Figure 5). The idea that the single pilot optionally intervenes but the automation primarily executes the functions is a fundamental difference to the function allocation concept for dual pilot operations, where the pilot primarily executes the functions while automation can optionally be used (cf. "Optional automation" in Figure 4). Another main difference between dual and single pilot operations is that during dual pilot operations, both pilots are in charge of monitoring the health condition of the other pilot. This is obviously not possible during single pilot operations. As such, a pilot health monitoring system would have to be introduced that automatically informs the ground station operator of a pilot incapacitation. Another option could be to provide the ground station operator with direct visual feedback from the cockpit via a video stream. However, this approach would require the ground station operator to constantly monitor the video stream. Therefore, the introduction of a pilot health monitoring system, that informs the ground station operator in case an incapacitation has occurred, seems to be the more suitable option. After the ground station operator has been informed, they can still request video feedback from the cockpit for confirmation purposes or try to contact the single pilot via radio or voice data link.

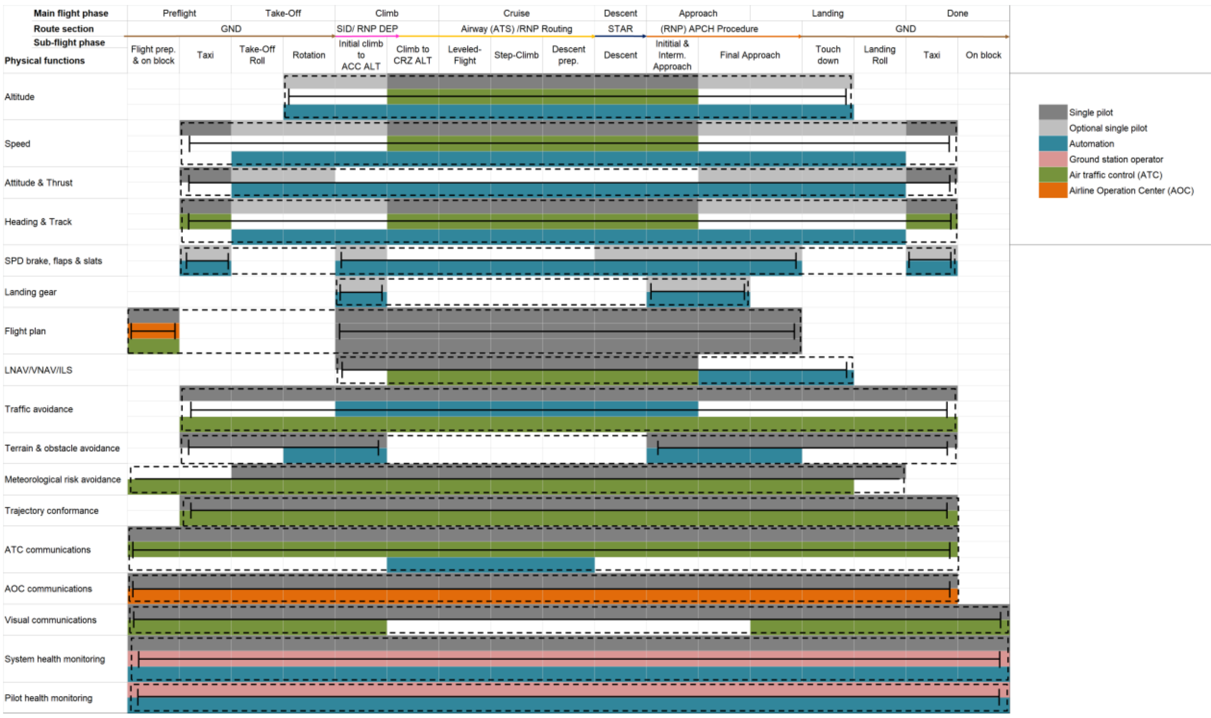


Figure 5. SOCA-CAT for single pilot operations including a ground station for supervising system and pilot health.

3.2.3 SOCA-CAT for remote-single pilot operations

Controlling an aircraft from a remote location on the ground, instead of from the cockpit inside the aircraft, has a major implication on the accessibility of potentially important information for making safety critical decisions (Williams, 2008; Friedrich, Papenfuß & Hasselberg, 2018). The remote pilot is especially deprived of sensory, i.e. visual, auditory, vestibular, haptic and olfactory information. Furthermore, delays in control inputs will most likely occur due to the physical distance between the aircraft and the ground control station. Friedrich, Papenfuß & Hasselberg (2018) used methods from cognitive work analysis to investigate impacts of transitioning from conventional to remote aircraft control on function allocation and information accessibility. They conclude that especially during landing phases, the information that is gathered from the environment seems to play a major role for deciding whether the aircraft is behaving normally or not and whether any measures need to be initiated. If the pilot does not have access to sensory information anymore, this might heavily affect the quality of the decisions.

Consequently, the shift from single to remote-single pilot operations will most likely necessitate the allocation of even more functions to the automation. This applies especially for functions that require the availability of sensory information, such as the classic aviate functions, such as controlling the attitude and thrust. Manual flying will most certainly not be possible anymore during remote aircraft control and the remote pilot will control the aircraft through high level commands for changing the altitude for example. While the remote pilot controls the autopilot to change altitude, speed and heading of the aircraft (according to ATC instructions), the automation will have to completely execute the attitude and thrust function. Figure 6 illustrates the SOCA-CAT showing a possible function allocation concept for remote-single pilot operation of a CS-25 certified aircraft flying in controlled airspace.

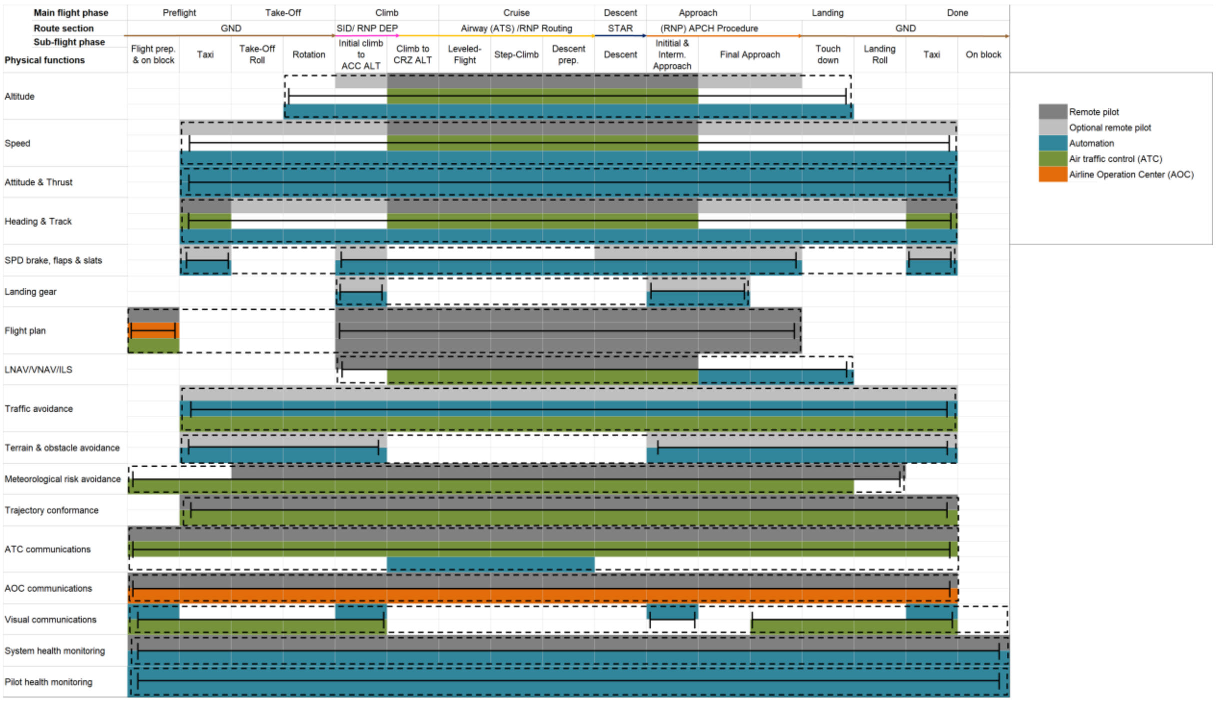


Figure 6. SOCA-CAT for single-remote pilot operations.

This subsection presented the developed flight task models and function allocation concepts for dual, single and remote-single pilot operations. In the next chapter, for selected functions and flight phases, the interaction between the different actors will be described in more detail. For this purpose, the functions and flight phases were selected, where the effect of reducing the number of cockpit crew and shifting from conventional to remote control is most obvious and critical.

4 Interactions between the involved actors

This chapter describes the interactions between the involved actors (e.g. ATC, AOCC, PF and PM) for specific aircraft functions and tasks (e.g. changing altitude, manage high lift devices, aircraft system health monitoring, etc.) in dedicated flight phases (e.g. final approach). Hereby we focus on some particular examples of aircraft functions, and especially highlight the differences in the foreseen interactions depending on the chosen aircraft configuration (i.e. dual piloted aircraft, single piloted aircraft or remote piloted aircraft). One key objective is to describe the underlying high-level concept of the interaction between the actors, and analysing the similarities and differences for the varying aircraft configurations.

Each figure is split into columns, each of which represents a different actor (e.g. PF). Mandatory interactions are represented as solid black lines. A dotted black line represents interactions that do not necessarily occur, especially under standard operating procedures. The automation for example notifies the pilots if the aircraft's sink rate is too high. This interaction is not mandatory. However, it will occur if the sink rate is out of the normal range and poses a safety risk. A dotted red line represents interactions that require new technology or automation that is currently not available for commercial aircraft. For instance, pilot health monitoring in a single piloted aircraft will (most likely) rely on a pilot health monitoring system (e.g. based on physiological data of the pilot) which is currently not available in CS-25 aircraft. The next subsection will describe the interaction between involved actors for reacting to ATC instructions.

4.1 Reacting to ATC instructions

Figure 7 shows the interaction between ATC, the PM, PF and the automation for current dual pilot operations. The interaction starts with ATC issuing a clearance or an instruction via radio, such as "reduce speed 280 knots". The PM reads back the instruction to ATC, while the PF inserts the new speed value into the autopilot (AP). After the value has been entered, the automation executes the necessary actions to reduce the speed to 280 knots (e.g. by reducing thrust). In order to assure that the aircraft in fact slows down to the instructed value, ATC, the PM and the PF monitor the speed value. The same procedure can be applied to every ATC clearance or instruction.

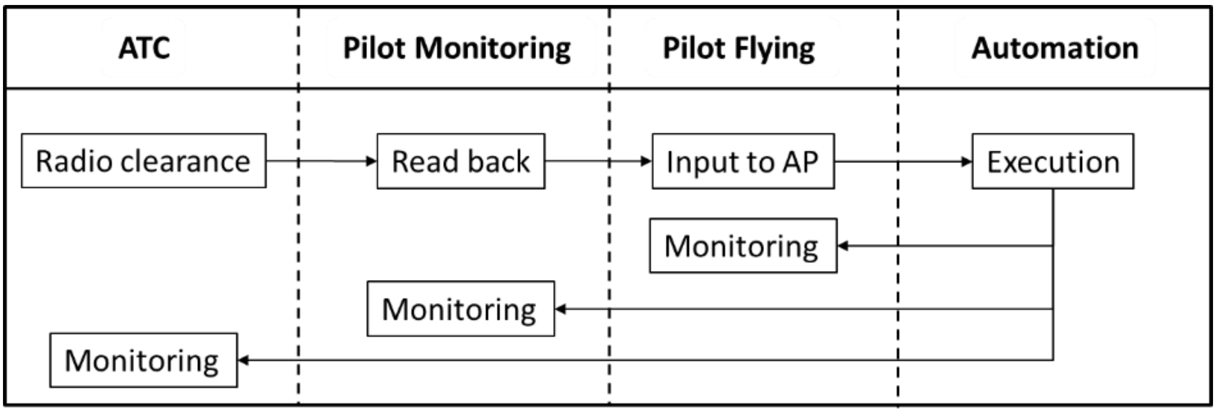


Figure 7. Interaction plot for changing altitude, speed or heading as requested by ATC in dual pilot operations. AP = autopilot

The upper part of Figure 8 presents the required interactions for reacting to ATC clearances or instructions in case of single pilot operations with a potential ground station monitoring the flight. The interaction is basically the same as for dual pilot operations (cf. Figure 7) with the difference that the single pilot does both, the read back and the input to AP. As obvious from Figure 8, during single pilot operations there is one monitoring instance less than for dual pilot operations. Therefore, we included the possibility of the ground station to monitor and thus take over the monitoring duties of one of the pilots in Figure 7 (shown with the dotted, red line in Figure 8). Another possibility could be to introduce another automation instance to assist single pilot. An example is shown in the lower part in the monitoring.

The lower part of Figure 8 shows another possibility for interaction that assumes more automation involvement. This concept foresees that ATC issues their clearance via radio and data link. The information transmitted via the datalink is automatically received by the AP and the single pilot only has to confirm and read back. This would relieve the single pilot of the duty of putting the values into the AP themselves. After the single pilot confirmed the new value, the automation would execute the necessary actions.

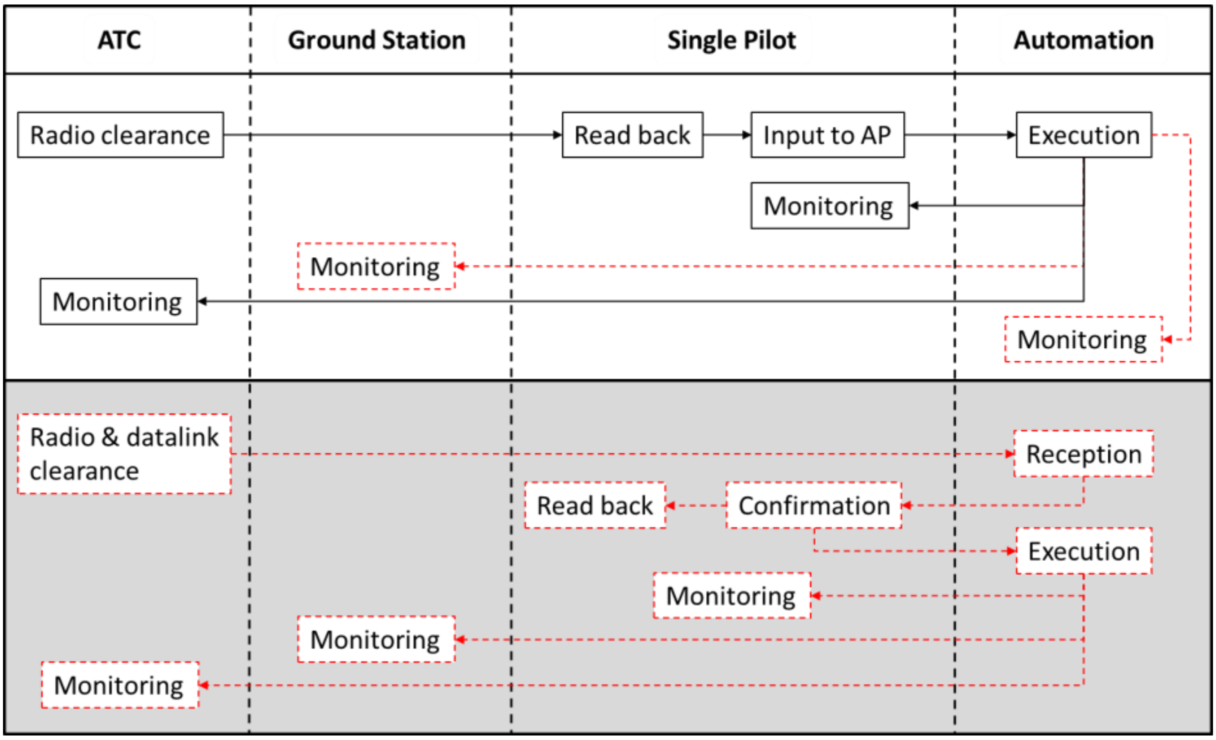


Figure 8. Interaction plot for changing altitude, speed or heading as requested by ATC in single pilot operations.

The move to remote-single pilot operations again has a major implication on the monitoring instances. In contrast to the single pilot operation interaction concept in Figure 8, there is no possibility to include a third monitoring instance. As such, the monitoring duty would be allocated only to the remote-single pilot and ATC. Again, a possibility could be to allocate this monitoring role to the automation.

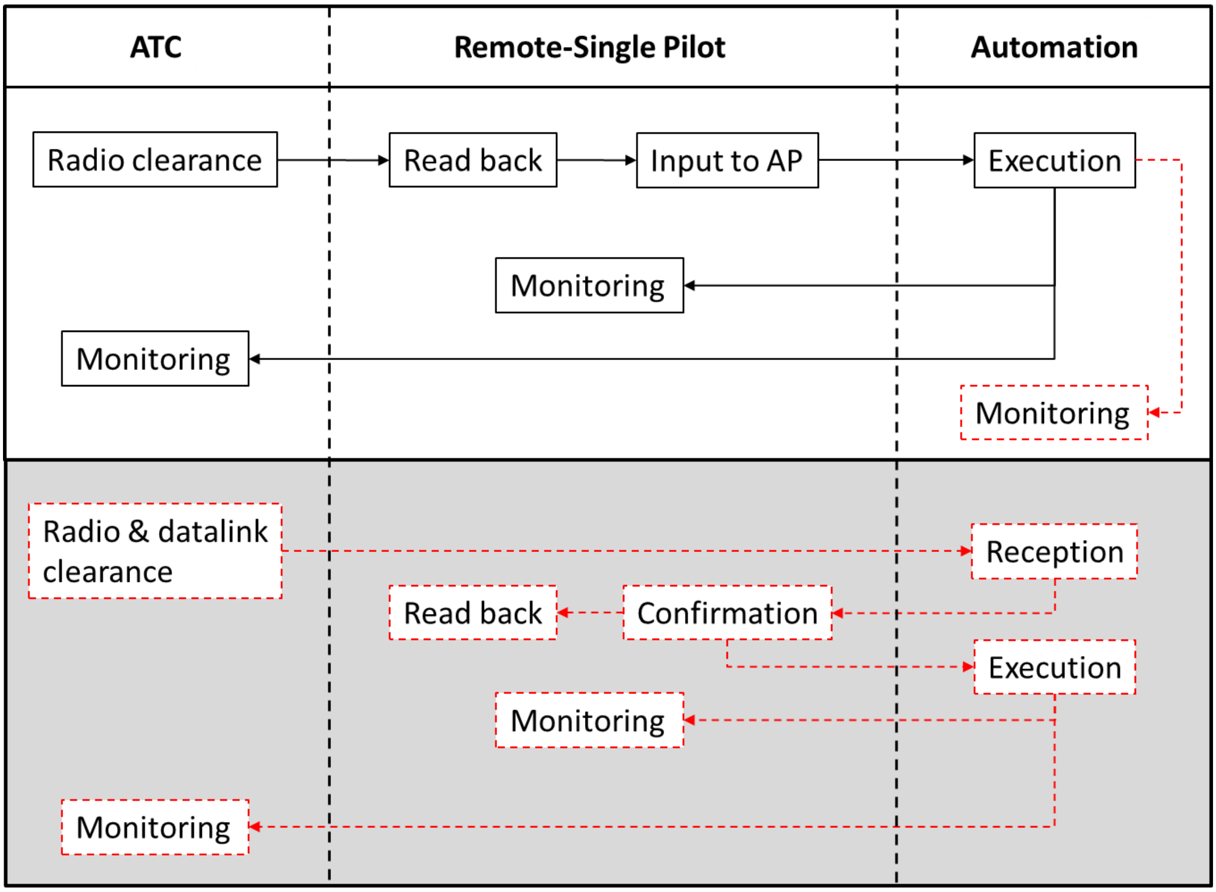


Figure 9. Interaction plot for changing altitude, speed or heading as requested by ATC in remote-single pilot operations.

4.2 Aviate the aircraft during final approach

This subsection presents the interactions regarding aviation of the aircraft during the final approach. This example was selected, because it very well illustrates how reducing the cockpit crew and moving the pilot to the ground affects the interaction between the involved actors. In this context, aviation comprises the functions speed, altitude, heading, thrust and attitude. Figure 10 presents the interactions between ATC, PM, PF and the automation during a manual approach. The PF executes all the required activities to manually fly the aircraft while the PM monitors these activities. Simultaneously ATC and the automation monitor various parameters, such as the altitude, speed or the sink rate and issue a warning, if any parameter exceeds the limits of safe operation (e.g. exceeding the flight envelope due to low speed or approaching terrain). For an instrument approach, the interaction is reversed. In this case, the automation executes the aviate functions while both pilots and the automation itself monitor (cf. Figure 11).

Similarly, to the interactions described in the previous subsection, the move from dual to single pilot operations leads to the reduction of a monitoring instance, if no ground station is involved. The interactions during manual and instrument approaches for single pilot operations are presented in Figure 12 and Figure 13.

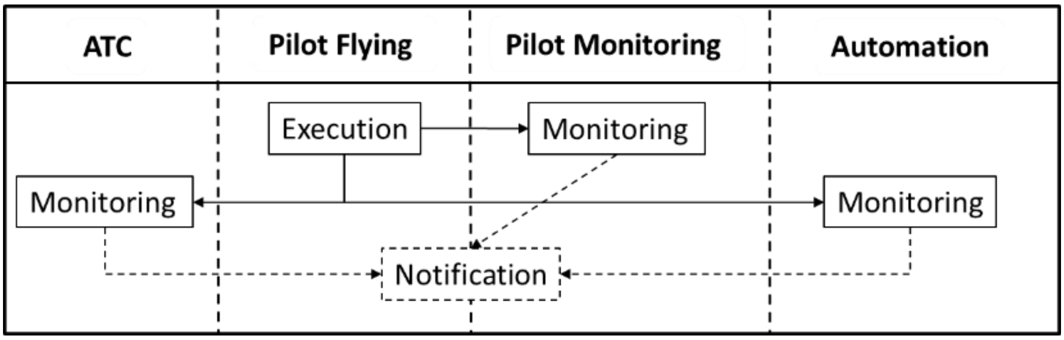


Figure 10. Interactions between the pilot flying, pilot monitoring and the automation during a manual approach for the aviate functions attitude, thrust, speed and altitude.

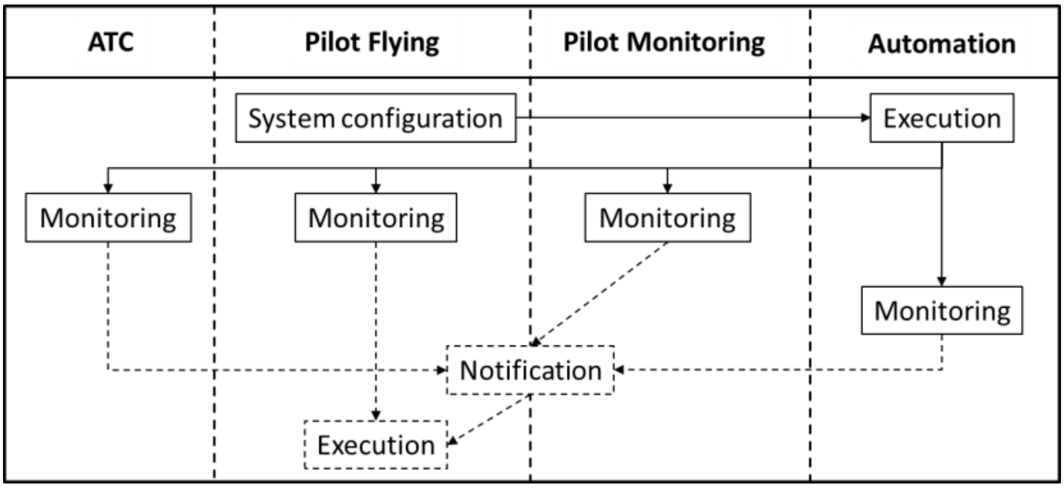


Figure 11. Interactions between the pilot flying, pilot monitoring and the automation during an instrument approach for the aviate-functions attitude, thrust, speed and altitude.

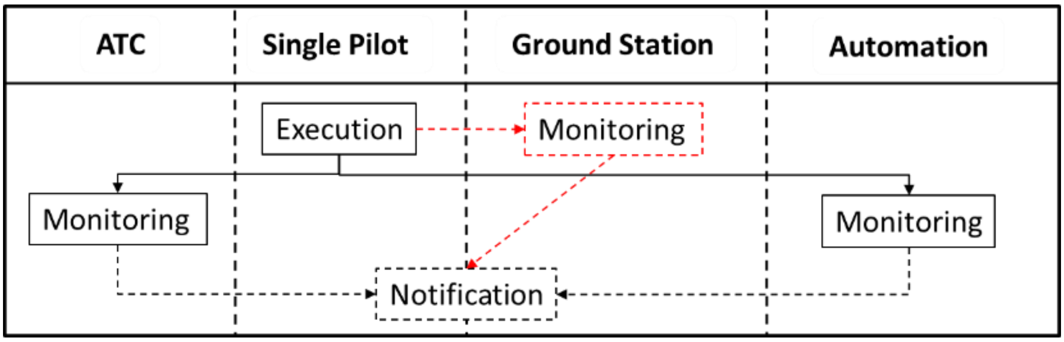


Figure 12. Interactions between the single pilot, a potential ground station and the automation during a manual approach for the aviate functions attitude, thrust, speed and altitude.

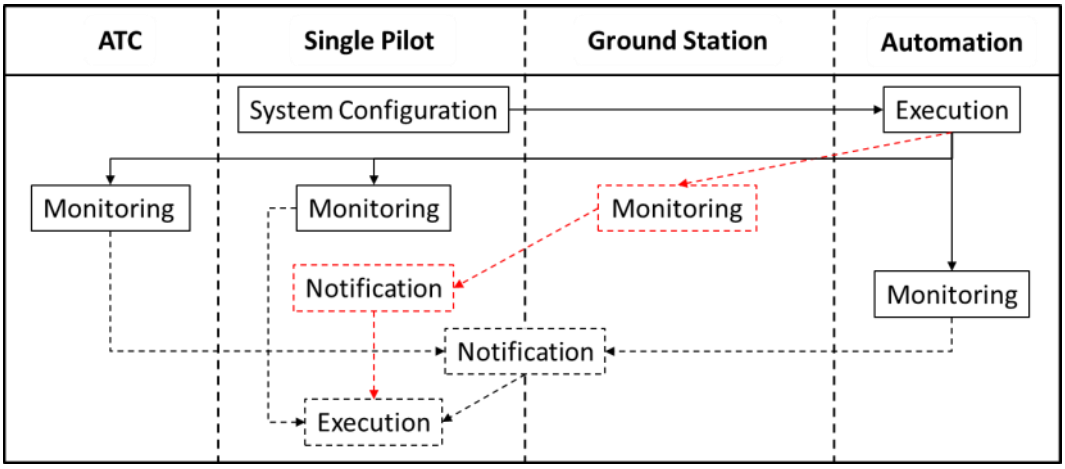


Figure 13. Interactions between the single pilot, a potential ground station and the automation during an instrument approach for the aviate functions attitude, thrust, speed and altitude.

In remote-single pilot operations the interactions again change fundamentally. Since the remote pilot lacks sensory information, which appears to be especially important for making decisions during manual final approaches (Friedrich, Papenfuß & Hasselberg, 2018), the interaction concept does not foresee manual flight operation (at least during standard operating procedures). Consequently, the automation executes and the remote pilot monitors. In case of a safety critical situation that requires counter measures, the automation issues a notification to the remote pilot. Figure 14 presents two different options for interaction. The core difference is that in the first option (presented in the upper part of Figure 14) the remote pilot intervenes (either by issuing high level commands to the autopilot or actually take over manually) after being notified and in the second option (lower part of Figure 14) the automation intervenes with the remote pilot always having the possibility to overwrite the automation and take over control. However, if the remote pilot is supposed to take over manual control of the aircraft with only limited access to potentially important sensory information it needs to be assured the ground station provides means to compensate for the loss of sensory information, such as a camera view or alike.

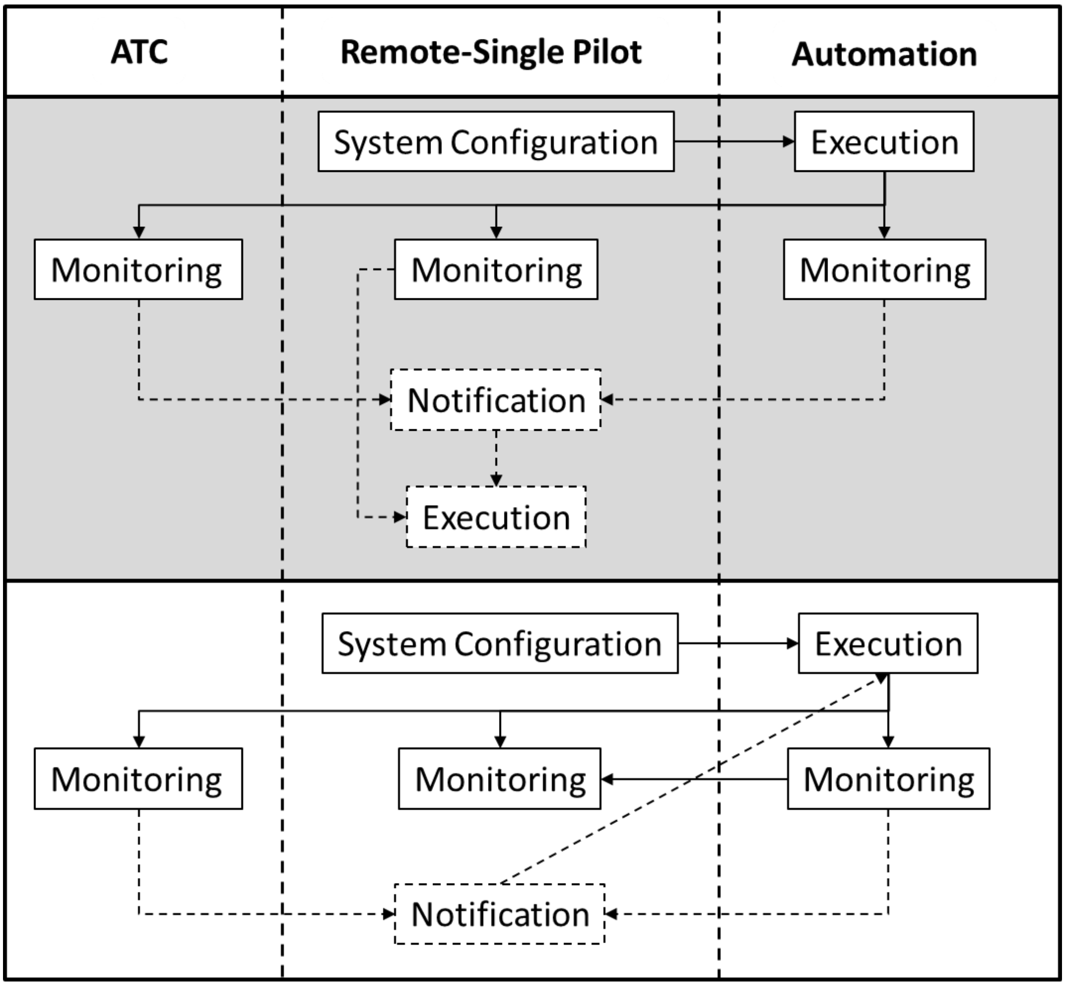
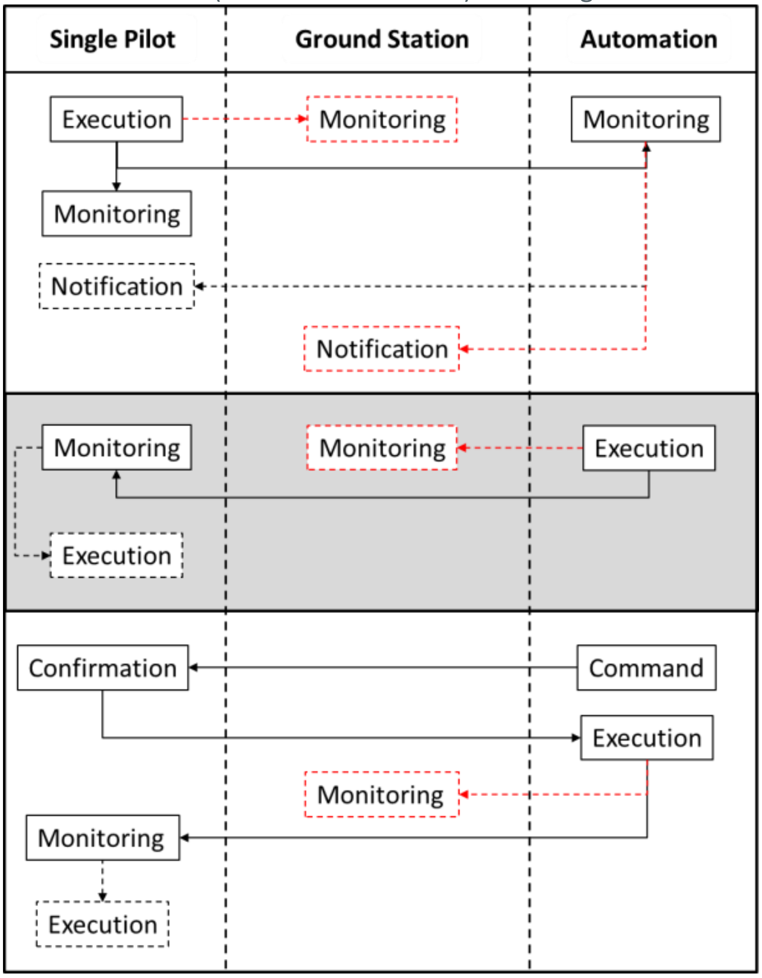


Figure 14. Interactions between the remote-single pilot and the automation during an instrument approach for the aviate functions attitude, thrust, speed and altitude.

4.3 Managing high lift devices and the landing gear

This subsection focuses on managing the high lift devices and the landing gear during initial climb and intermediate and final approach. The most common procedure in dual pilot operations is depicted in Figure 15 The PF commands for example the deflection of flaps ("Flaps 2") or the extraction of the landing gear ("Gear down"). The PM reads back the command and operates the respective levers. Both, the PF and the PM then monitor, if the flaps actually deflect or the gear extracts.

Figure 16 shows three different options how managing high lift devices could be carried out in single pilot operations. Since the second pilot is omitted as a control instance, automation would have to take over this control instance and notify the single pilot when the flaps or the landing gear did not extend or at the right time. If a ground station were introduced, the ground station operator could assist in monitoring and being given notification from the automation, if something is wrong or the gear was not or could not be extended (for whatever reason). This is again shown using red, dotted



lines in Figure 16. Another possibility would be to make the automation execute, i.e. deflect the flaps for example, and have the single pilot as well as the potential ground station operator monitor the automation. This interaction concept is visualized in the middle row of Figure 16. The third concept involves the automation asking for a clearance to deflecting the flaps and the single pilot confirming the intended action. Subsequently, the automation would execute the function and the single pilot and ground station operator would monitor again. It should be noted that these two latter interaction concepts assume that the single pilot still has power to overwrite the automation.

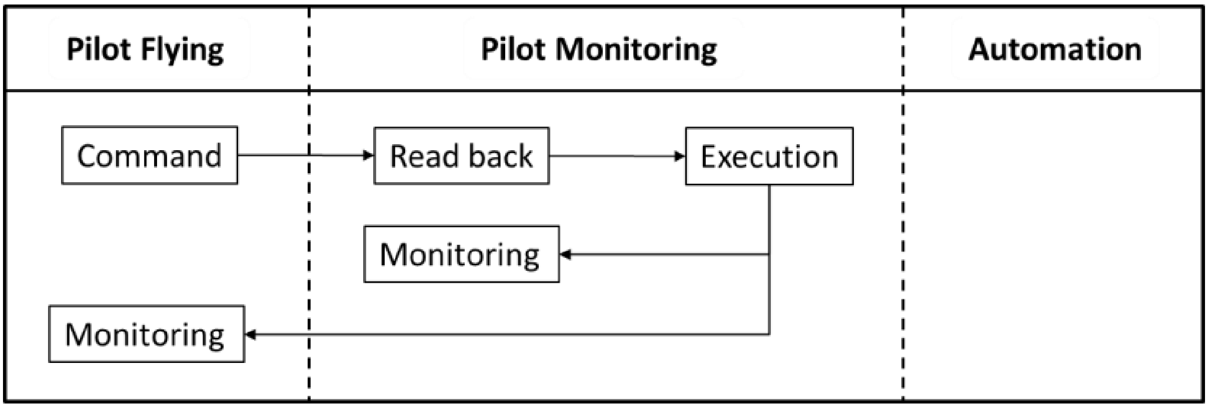


Figure 15. Interactions between the pilot flying, pilot monitoring and the automation for managing high lift devices and the landing gear.

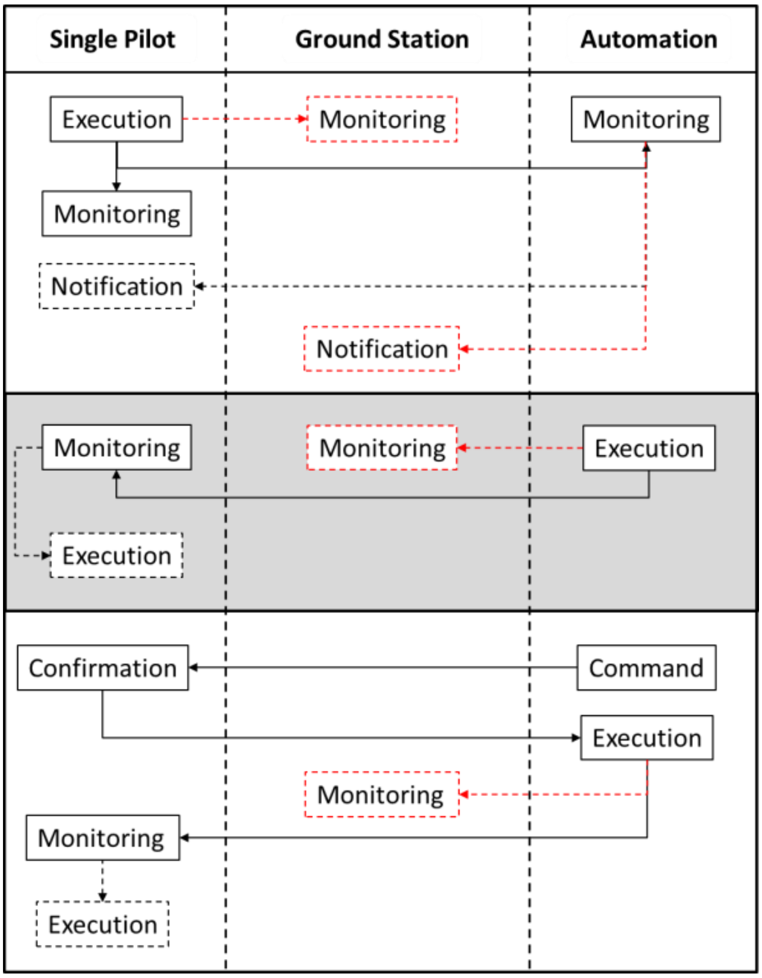


Figure 16. Interactions between the single pilot, a potential ground station and the automation for managing high lift devices and the landing gear. The figure shows three possible interaction concepts.

The two latter interaction concepts of Figure 16 can be applied to derive an interaction concept for remote-single pilot operations. The difference to the single pilot concept is that in remote-single pilot operations, the remote-single pilot is the only monitoring instance. Manual management of high lift devices were omitted for remote-single pilot control (at least for standard operating procedures), due to the previously described effects of lacking sensory information. However, the remote-single pilot should always have the authority of the aircraft and be able to overwrite the automation, which in this case means manually managing the high lift devices and the gear, if the need arises. The two interaction concepts are presented in Figure 17.

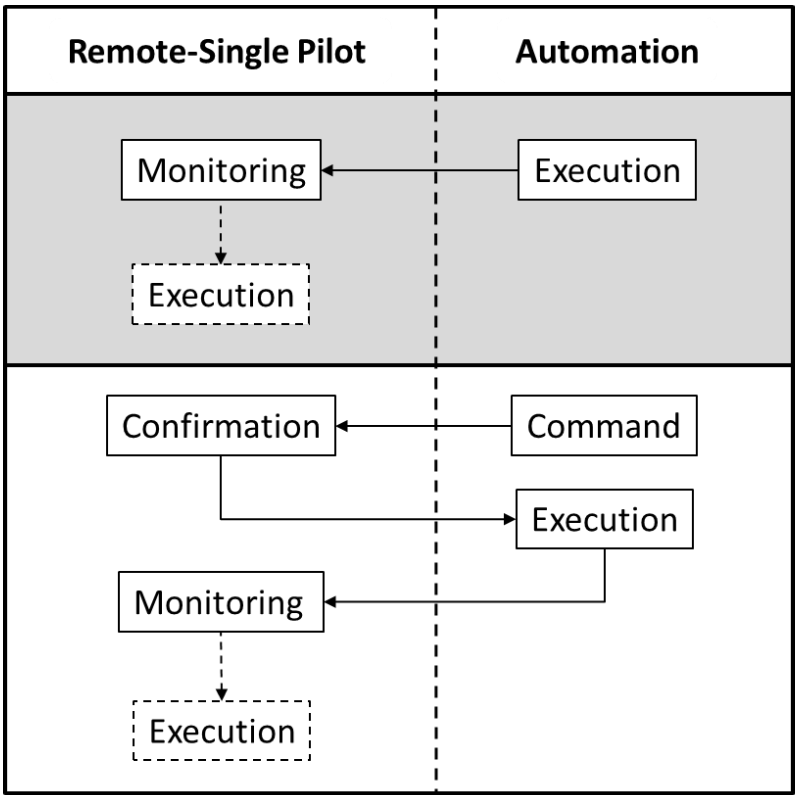
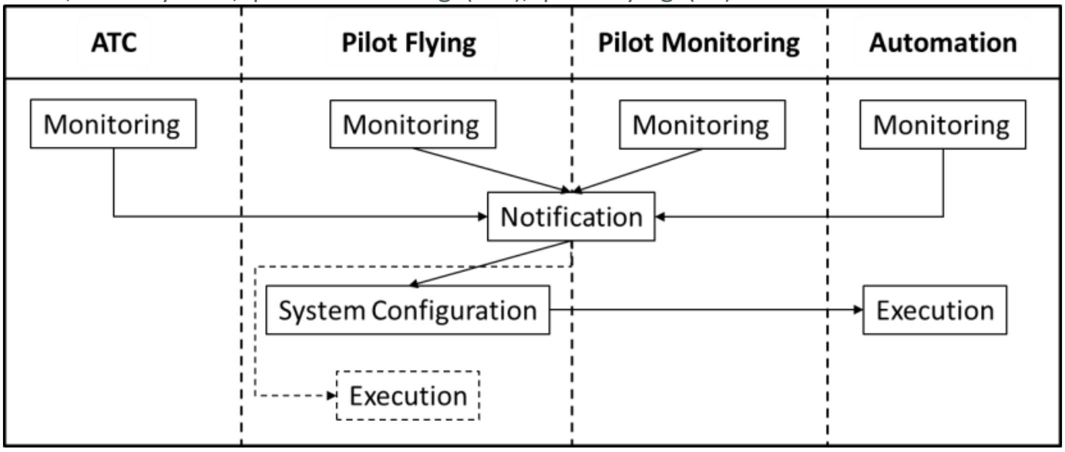


Figure 17. Interactions between the remote-single pilot and the automation for managing high lift devices and the landing gear. The figure shows two possible interaction concepts.

4.4 Traffic avoidance

One key element of maintaining flight safety is traffic avoidance, both on ground (e.g. during taxiing) and in air (i.e. whilst flying). This task is required to be conducted in all flight phases, and from four main actors, namely ATC, pilot monitoring (PM), pilot flying (PF) and on-board automation (e.g.



TCAS).

Figure 18 illustrates the interaction between the involved actors.

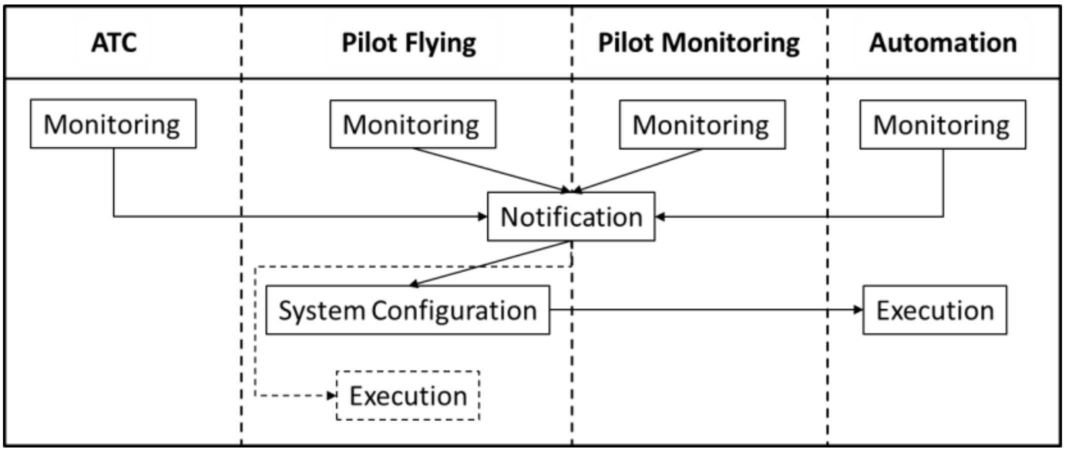


Figure 18. Interaction plot in case of traffic avoidance for a dual piloted aircraft

It has to be noted, that in aviation separation between aircraft are maintained by following the “Well clear” guideline, which defines a separation minima depending on the flight level and aircraft type (ICAO, 2016). However, the interaction between the actors remain the same independent of these factors. All four actors are constantly monitoring the near vicinity of the aircraft, in order to identify if other traffic (ground or air) might interfere the planned trajectory. In case the required separation minima cannot be maintained, each actor is capable of issuing a notification e.g. via voice or radio communication in order to inform the others of the imminent risk of a collision. Based on this notification the PF will manipulate the autopilot system (e.g. pilot changes altitude) on which the aircraft executes an evasive aircraft manoeuvre in order to prevent the collision.

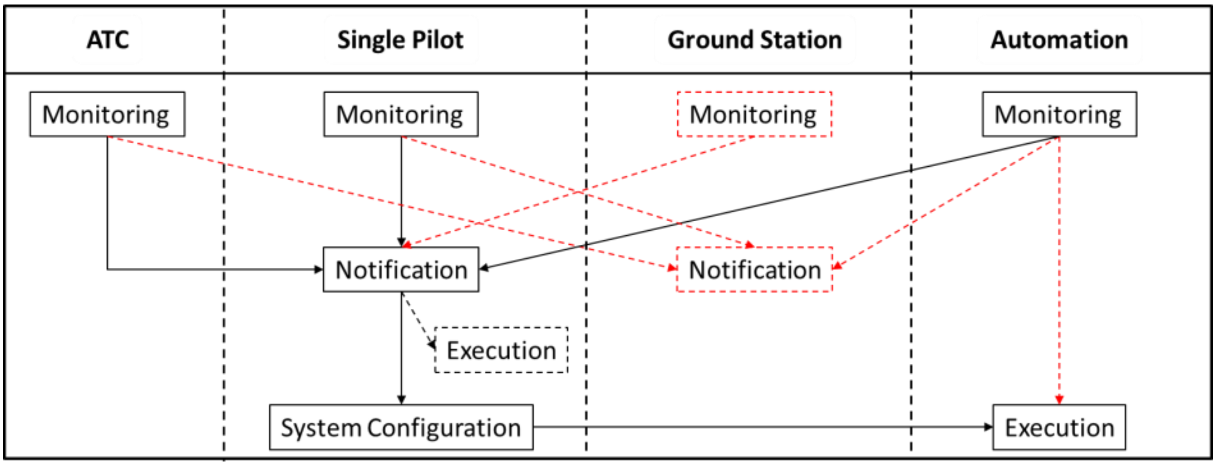


Figure 19 depicts the interactions between the involved actors for a single piloted aircraft supported by a ground station (GS) in a traffic avoidance situation. Hereby we assume that a ground station operator (GSO) is monitoring the flight. In consequence, four main actors are involved, namely ATC, single pilot, GS and on-board automation. The red dotted lines illustrate future aircraft or ground technology that are currently not involved in a flight of an CS-25 aircraft. As soon as an imminent risk of a collision with other traffic is identified – by any of the involved actors – a notification will be issued. On the one hand to the single pilot (PF), and on the other hand to the GSO. Upon this notification the single pilot will manipulate the autopilot system upon which the aircraft executes an evasive manoeuvre. In case the single pilot is not capable of executing this manoeuvre (to whatever reason) on-board automation will conduct this evasive aircraft manoeuvre on its own. The main difference between a dual piloted aircraft compared to a single piloted aircraft support by a GS in a traffic avoidance instant with respect to the interaction between the actors, is the location of the PM which is represented by the GS in

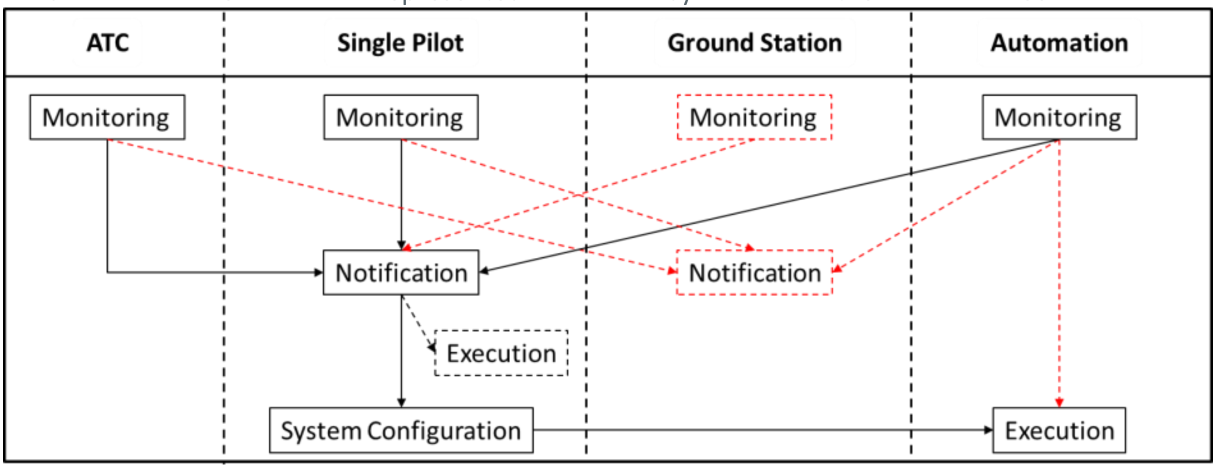


Figure 19. In addition, it can be foreseen that a future single pilot CS-25 aircraft might have automation on-board which is capable of, and authorized to, execute an evasive aircraft manoeuvre in case it is required (e.g. single pilot incapacitation). This possibility is illustrated via the dotted red

lines in

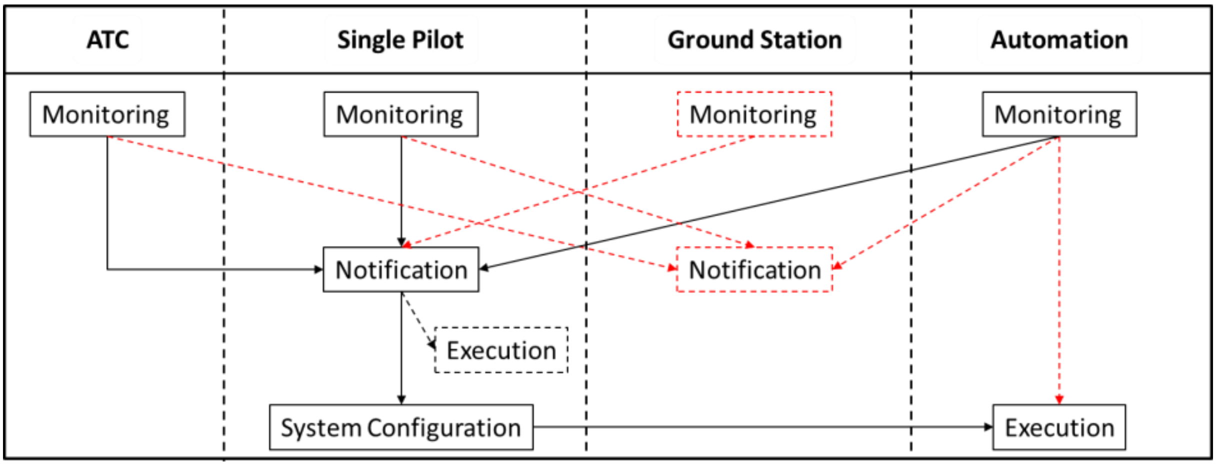


Figure 19.

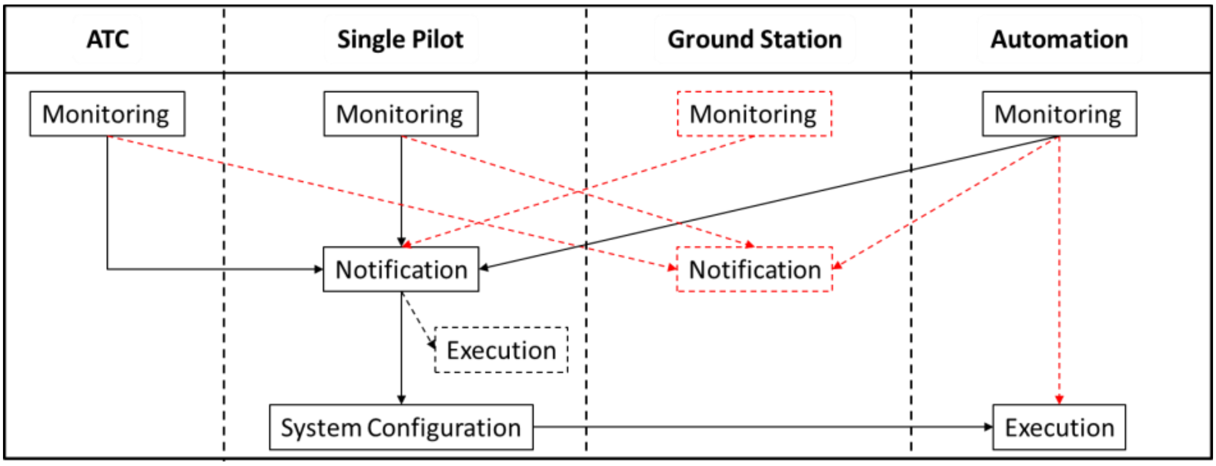


Figure 19. Interaction plot in case of traffic avoidance for a single piloted aircraft.

Figure 20 shows the interactions between the involved actors for a remote-single piloted aircraft in case of traffic avoidance. In a remote-single piloted aircraft there is one monitoring actor less compared to a single-piloted aircraft. In total, (only) three actors are monitoring the near vicinity of the aircraft, namely ATC, remote-single pilot, and automation. However, again, as soon as an imminent risk of a collision is identified the remote-single pilot (PF) will be notified. Upon this notification on evasive manoeuvre will be execute. The red dotted line illustrates a future automation technology that is capable of, and authorized to, execute an evasive aircraft manoeuvre on its own in case of conflicting traffic.

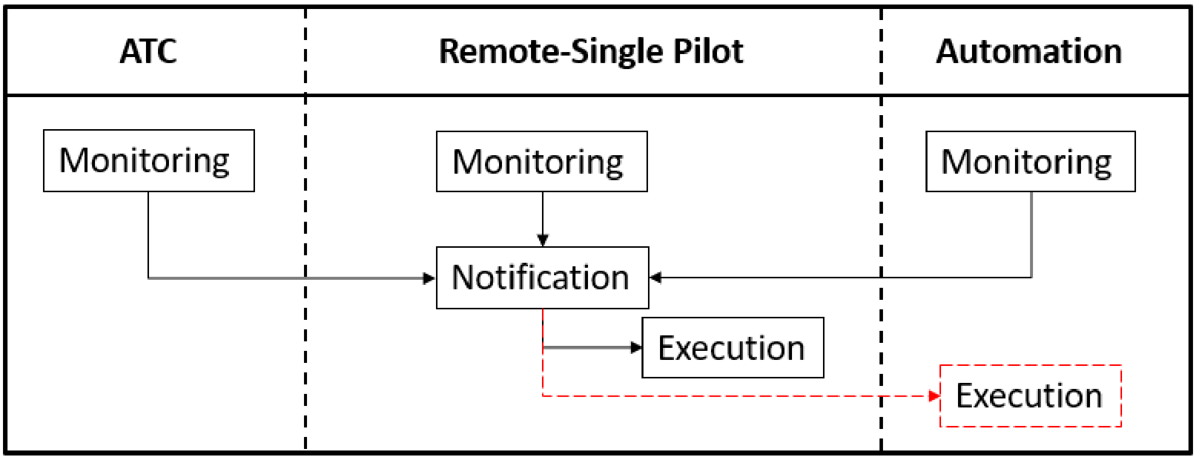


Figure 20. Interaction plot in case of traffic avoidance for a remote piloted aircraft.

4.5 Aircraft system health monitoring

As an additional example, the interactions between the involved actors for the aircraft system health monitoring has been chosen.

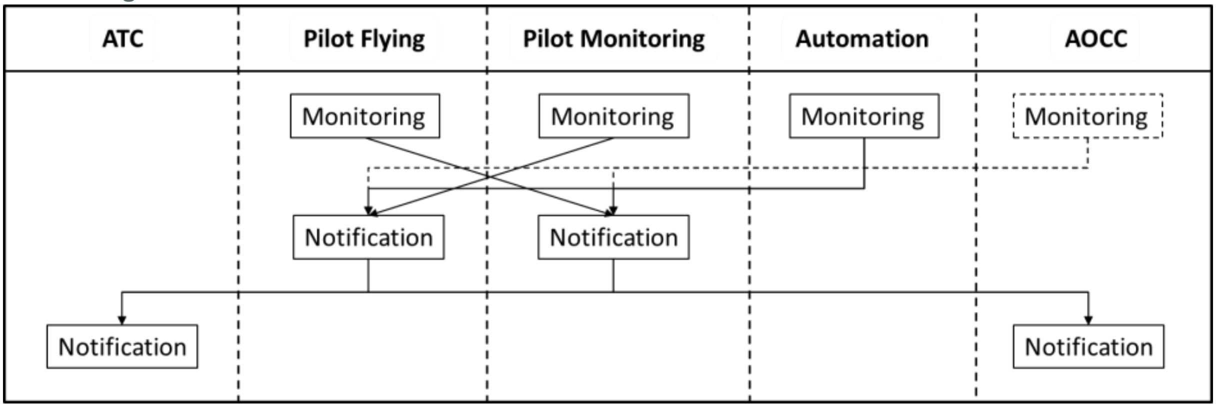


Figure 21 illustrates the interaction required to be conducted for monitoring the aircraft system health for a dual piloted aircraft. In total, five main actors are involved namely the PF, the PM, ATC, AOCC and on-board automation. Four of the five actors are constantly obliged to monitor the aircraft systems during all flight phases – here PF, PM, AOCC and automation. However, it has to be noted, that AOCC is only able to monitor the aircraft system health of specific aircraft within their airline fleet. In case of a malfunction of an aircraft system or abnormal system parameters the PM as well as the PF will be notified (e.g. via voice communication between PF and PM, warning signal in the cockpit, etc). This notification may originate from one of the pilots, the automation or in certain cases from AOCC. Depending on the severity of the system abnormality (e.g. engine failure) the cockpit crew will notify ATC and AOCC about the aircraft system malfunction. In consequence, a mitigation action (e.g. emergency landing) might need to be conducted. However, this mitigation action is not part of the depicted aircraft system health monitoring function.

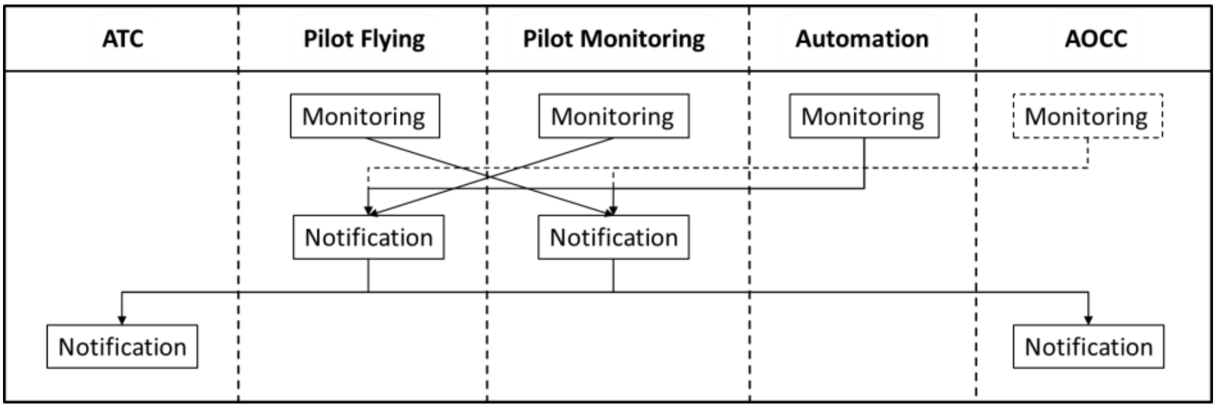


Figure 21. Interaction plot for aircraft system health monitoring in a dual piloted aircraft.

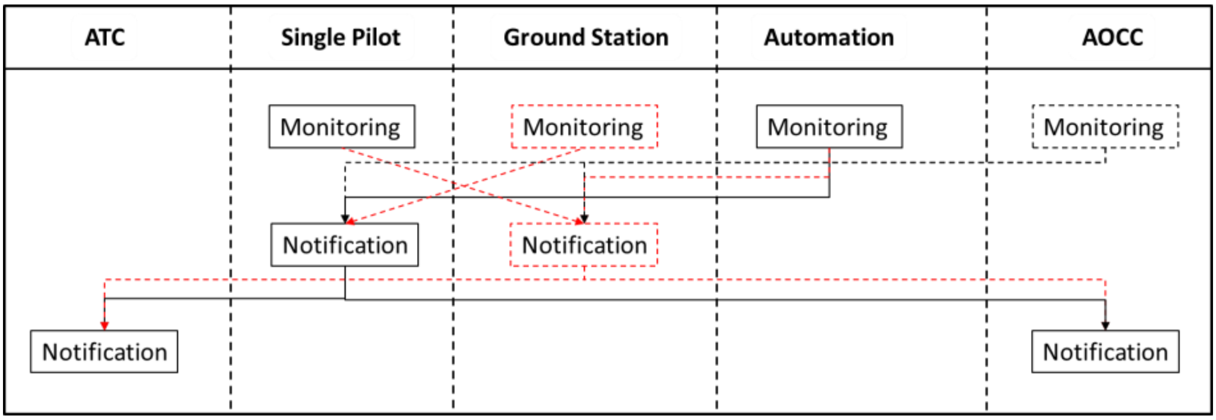


Figure 22 shows the interaction between the involved actors for the monitoring of the aircraft system health for a single piloted aircraft supported by a GS. Again, four of the five actors are constantly monitoring the aircraft system health parameters during all flight phases.

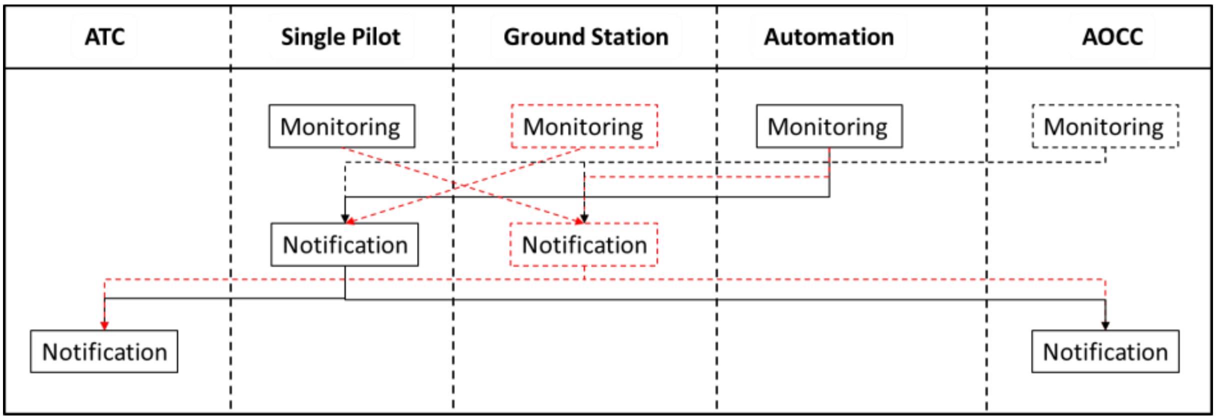


Figure 22. Interaction plot for aircraft system health monitoring for a single piloted aircraft.

The main difference compared to a dual piloted aircraft is the involvement of a future GSO who is basically taking the role of the PM. In order to clearly visualize the interaction of the future GS system with the other actors we have chosen the red dotted lines representing interaction activities that are currently not in place.

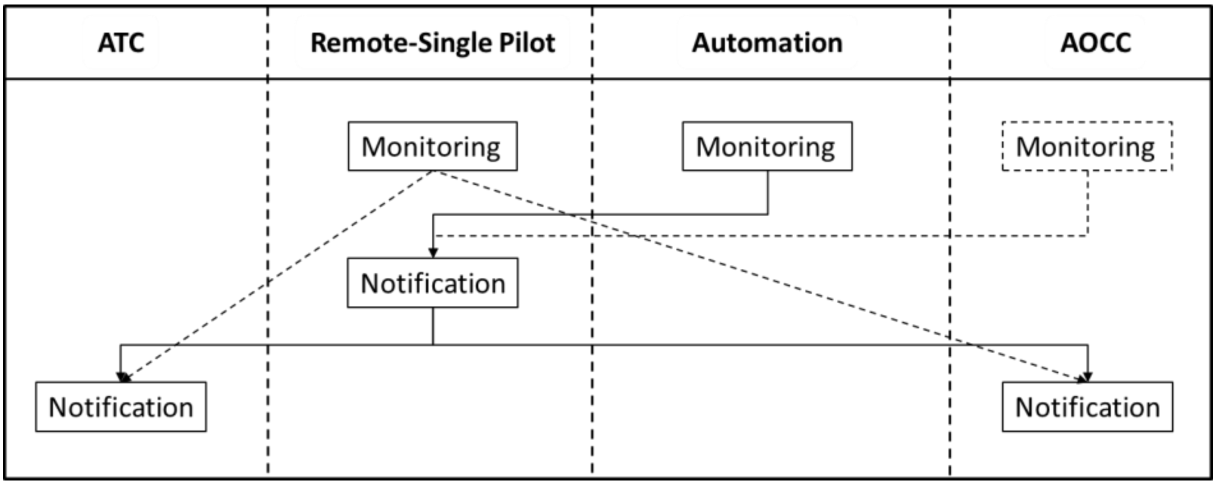


Figure 23 depicts the interactions between the involved actors for monitoring the aircraft system health for a remote piloted aircraft. In this case, four actors are involved – namely, the remote pilot, ATC, AOCC and on-board automation. The remote pilot as well as the automation are constantly monitoring the aircraft system health parameters. In addition, AOCC is capable of monitoring certain aircraft system parameter as well (this is the reason for the dotted lines). Again, as soon as an abnormal system parameter is detected the remote pilot will be notified (e.g. via warning signal, display icon, radio communication from AOCC, etc.). Similar to the case for a dual or single piloted aircraft, ATC and AOCC will be notified depending on the severity of the malfunction (this is the reason for the dotted lines).

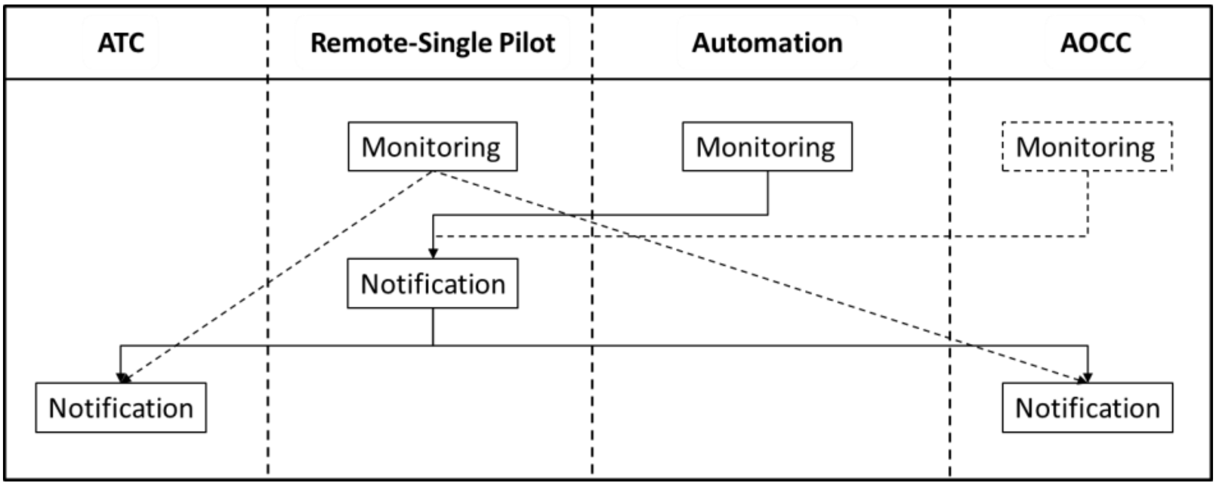


Figure 23. Interaction plot for aircraft system health monitoring for a remote piloted aircraft.

The main difference in a remote piloted aircraft compared to a dual or single piloted aircraft is the lack of one monitoring actors (PM or GS) in the process. As a result, a remote piloted aircraft will have to rely on two to three actors monitoring the aircraft system health parameter during the flight.

4.6 Pilot health monitoring

As a final example, the pilot health monitoring has been chosen. One of the key SAFELAND project objective is to examine the interactions, roles and responsibilities of the involved actors especially in the landing phase of a single piloted aircraft in case of a severe abnormal pilot health condition – the pilot incapacitation.

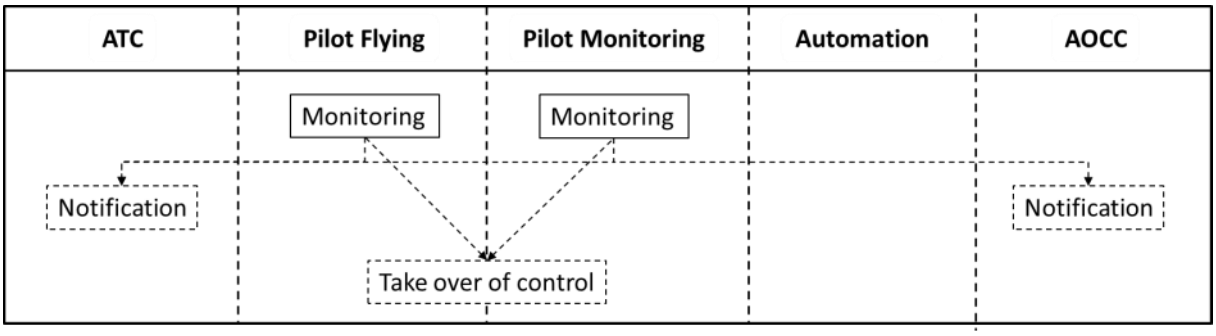


Figure 24 illustrates the interactions with respect to the pilot health monitoring for a dual piloted aircraft. In principle, only the PF and the PM on board of the aircraft are monitoring the health state of each other. In case the health condition of one of the two pilots deteriorates critically, and the flight cannot be continued as planned, ATC and subsequently AOCC will be notified. As a result, the remaining healthy pilot will have to take over the control, and land the aircraft safely. Finally, it can be noted, that on-board automation is not involved in this process for a currently operational dual piloted aircraft.

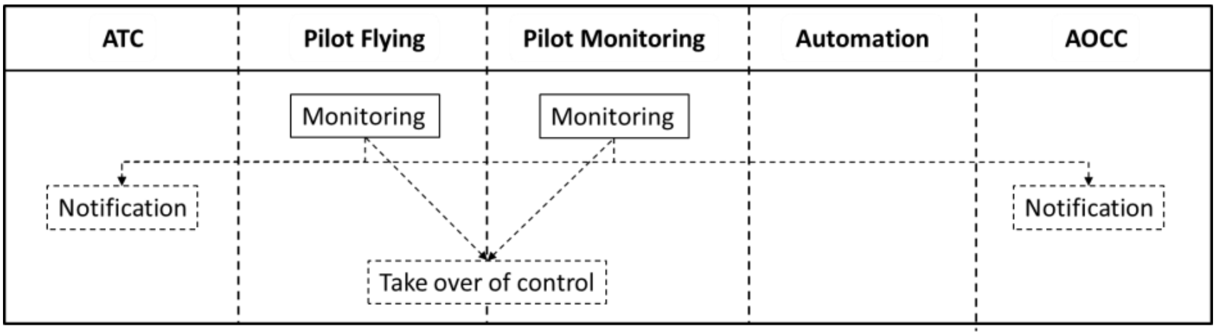


Figure 24. Interactions between ATC, AOCC, the pilot flying, pilot monitoring and the automation for monitoring pilot health.

As shown in Figure 25, pilot health monitoring in a single piloted aircraft supported by a GS involves five main actors: namely ATC, AOCC, the single pilot, GS and automation. As the red dotted lines in this figure illustrates, pilot health monitoring for single piloted CS-25 aircraft heavily relies on envisioned new technology (e.g. a future pilot monitoring system based on physiological health as for instance electrocardiogram (ECG) data, respiration and/or eye movement) that will need to be developed. However, the underlying principle for monitoring the pilot health is comparable to the principles shown for a dual piloted aircraft in

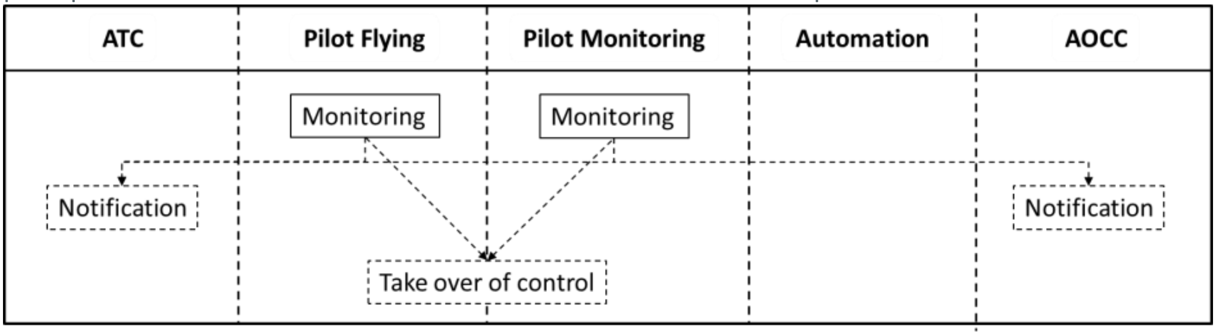


Figure 24.

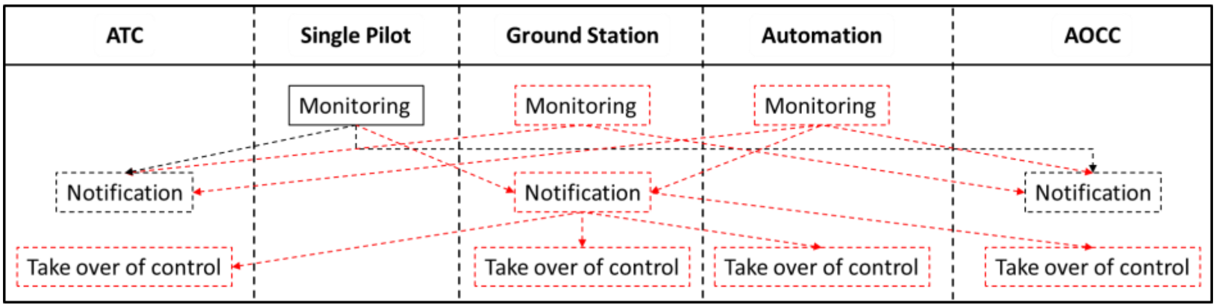


Figure 25. Interactions between ATC, AOCC, the single pilot, a potential ground station and the automation for monitoring pilot health.

Three of the five actors are constantly monitoring the pilot health state. In this case, a future on-board automation (e.g. pilot monitoring system) is recording and transmitting pilot health data to the GS. As soon as a critical pilot health state is detected, ATC, AOCC and the GSO will be notified. As a result, one or a combination several of the four involved actors ATC, GSO, AOCC or automation will have to take control of the aircraft, and subsequently land the aircraft safely. A feasible concept will be explored within the scope of the upcoming deliverables D1.2 *Initial Concept* and D1.4 *Final Concept* SAFELAND. These deliverables will also analyse in detail how a “take over of control” could be executed safely in case of a pilot incapacitation. Once transfer of control of the aircraft to a ground entity is successfully accomplished, the aircraft is being controlled remotely. As such, the result of the analyses will comprise one or multiple conceptual approaches for the transition of single to remote pilot control of an aircraft.

Figure 26 shows the interaction for pilot health monitoring for a remote-single piloted aircraft. In total, four actors are involved, namely ATC, AOCC, the remote-single pilot and on-board automation.

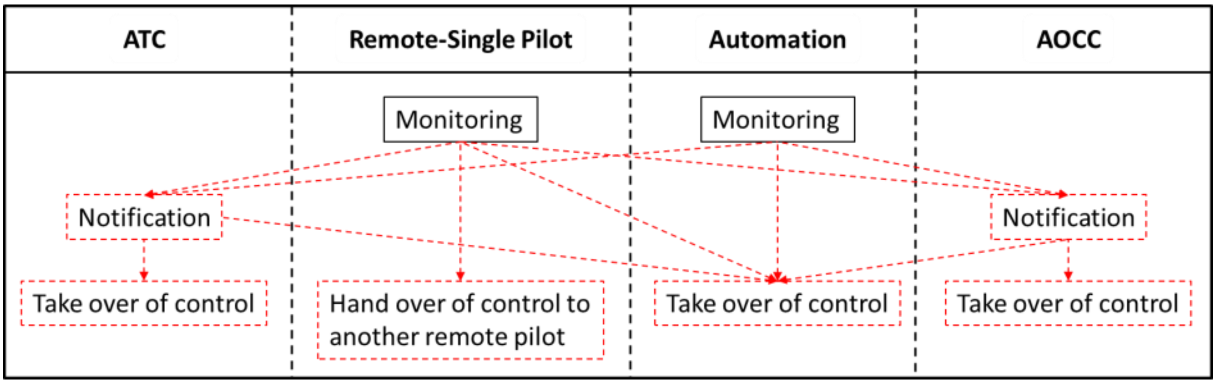


Figure 26. Interactions between ATC, AOCC, the remote-single pilot, a potential ground station and the automation for monitoring pilot health.

The pilot health monitoring for a remote-single piloted aircraft relies on an envisioned technology capable of analysing the remote pilots´ health (e.g. future pilot monitoring system). In case a critical remote-single pilot health state is detected, this on-ground automation will notify ATC and AOCC. Depending on the foreseen level of automation of the aircraft, the implemented air traffic management framework as well as regulatory constrains one of the three actors ATC, AOCC or on-board automation will take over the control of the aircraft, and land the aircraft safely.

5 Conclusions and next steps

This deliverable described the functions that need to be executed in order to enable safe flight operation of a CS-25 certified aircraft in controlled airspace. CWA was used to derive the functions and allocate them to the various involved actors. In a next step the interactions between the actors for selected functions and flight phases were described using a method closely related to OESDs. The analysis war carried out for dual, single and single-remotely piloted aircraft and the differences between the different aircraft configurations were discussed.

The analyses presented in this deliverable reveal important implications of reducing pilot crew and moving the pilot to the ground (which have been added to the assumptions list, see Paragraph 1.4):

- A comparison of the function allocation descriptions for dual, single and remote aircraft operations presented in Figures Figure 4, Figure 5 and Figure 6 clearly illustrate the need for more automation as a consequence of reducing the crew number and repositioning the pilot to the ground.
- The second implication is that even if the aircraft is controlled from the on-board flight deck by one pilot, ground support will be unavoidable. One of the ground entities involved (i.e. GS, AOC or ATC) will at least have to have access to the health data of the aircraft systems but also of the single pilot. The presented analyses assumed that the GSO will fulfil this role
- Consequently, the reduction of pilot crew will necessitate at least the introduction of a permanent data link to the aircraft, transmitting system and pilot health data. With regard to the latter, a pilot health monitoring system will need to be developed that constantly monitors the condition of the single pilot and informs an entity on the ground when pilot health is not ensured anymore, i.e. a pilot incapacitation occurred. If this is the case, aircraft control needs to be transferred to either the automation alone, which in turn lands the aircraft, and/or to other ground-based actors (cf. Figure 25).

The main objective in SAFELAND is to derive and evaluate various concepts for (1) transferring aircraft control and (2) controlling the aircraft from the ground. Hereby, different options of function allocation between the GSO, ATC and AOCC will be analysed and evaluated. In D1.2 Initial Concept, the different function allocation options will be derived and evaluated with regard to their feasibility. In a second step the most promising concepts will be chosen for further investigation and a final SAFELAND concept will be derived in D1.4 Final Concept SAFELAND.

6 References

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