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Abstract. This paper presents a high-fidelity task analysis. The analysis represents a bottom up approach. It examines the actions of the standard operating procedures jointly performed by the pilot flying and pilot monitoring operating a large airplane, i.e. an Airbus A320. The analysis of the activities considers the aviate, navigate, communicate and manage relationship, sequential and parallel execution, the related interface and information. The detailed analysis also investigates, how todays multi pilot operations concepts, like the task share of the two pilots, cross-checks or the four-eyes principle are implemented. Based on that, a possible re-assignment of actions is made towards enabling single pilot operation of a large airplane supported by an enhanced assistance. The paper describes the research context, current regulations of multi pilot and single pilot operation, related work, the method and an insight to major results. The depicted results and needs for future developments enabling single pilot operation with large airplanes are discussed.

Keywords: Aviation, Human Machine Interface, Men Machine Interaction, Automation and Assistance, NICo.

1 Introduction

Due to the evolution of avionics and the development of new technologies, commercial aviation has never been safer and more performant conducting its daily all-weather operation. Present and new technologies like Autoland or Remotely Piloted Aerial Systems (RPAS) cause the question whether large airplanes could be operated by just one pilot in the cockpit managing all operations, weather conditions, traffic situations, environmental circumstances as well as contingencies that can occur. At present, large airplanes are managed by two pilots – multi pilot operation (MPO).

At the beginning, large airplane crews consisted of up to five members – a radio operator, a navigator, a flight engineer, the first officer and the captain. Towards the reduction of crew members and an increased level of automation, the number of tasks to operate a commercial airplane with two pilots today more or less equals the number of tasks of former large airplanes with five-member crews. Advanced avionics just provide sophisticated automation and assistance functions that enable the two pilots to aviate, communicate, navigate, manage the aircraft systems and conducting the mission management.

In contrast to large airplanes [1], normal category airplanes, i.e. airplanes with a maximum of 19 passenger seating configuration and maximum take-off weight of 8.618 kg (19.000 pounds) [2], are mostly certified to be operated by a single pilot (Single Pilot Operation - SPO). For instance, the Cessna Citation business jets CJ1-CJ4 are certified for single and multi pilot operation. Since year 1998 the Cessna CJ1 jet can be flown with a maximum cruise speed of 720 km/h by one pilot [3]. “The CJ1 is extremely easy to fly and can be single-pilot operated. The Citation line was designed for forward-thinking businessmen that would fly their own private jets to and from business meetings, resulting in several automated systems and a simple avionics system. For those that don’t plan to fly their own jet, its ability to be flown by a single pilot offers greater flexibility in flight operations and reduced direct operating costs.” [3,4]

Even though the essential operational tasks concerning to aviate, navigate and communicate might be “easy” to fulfill, the mission management, solving contingencies and demanding environments must be handled seriously and reliably too. Hence, what are the differences between the operation of a normal complex high-performance airplane with one and a large airplane with two pilots? What is necessary to cope with these different demands in order to operate large airplanes as safe and reliable as today in future with a single pilot – without being stressed, overloaded or precarious?

This paper presents a high-fidelity task analysis (HFTA). The goal of this analysis is to take a concrete view on the activities which are performed when operating a large airplane by two pilots. On the one hand the analysis outlines the implementation of the MPO concepts. On the other hand, it provides a concrete view on the task distribution and work share among the two pilots. The results build the baseline for future enhancements, extended automation and further needs of the next generation of cockpits.

This paper is structured as follows: It will introduce the research context, regulations concerning single and multi pilot operations, i.e. pilot licensing, aircraft certification and air operation regulations. Previous work as well as related work concerning other task analyses regarding single pilot operation with large aircraft will be outlined. The method and approach of the conducted high-fidelity task analysis will be presented, its results depicted and discussed.

2 Research context

In the institutionally funded research project “Next Generation Intelligent Cockpit” (NICo), DLR investigates the feasibility and needs for single pilot operation of large airplanes. The goal is the development of a main concept and functions for future highly automated cockpits. This goal is accompanied by the development and investigation of a Virtual and a Remote Co-pilot (VCP/RCP) in order to evaluate new ways to support pilots. The VCP comprises enhanced intelligent and robust automation and assistance. The RCP represents a qualified and educated ground-based remote pilot.

At the beginning of the project multi pilot crews and pilots also experienced with commercial single pilot operations were interviewed concerning the challenges when operating large and high-performance airplanes. Different aspects and situations were identified and transferred into an event catalog. Problematic situations, i.e. abnormal and emergency situations, were just named as one of the drivers for pilot's concerns related to single pilot operations with large aircraft. Surprisingly, many concerns referred to normal operation, like handling weather, traffic, specific airport issues or passengers. As a result, one focus for investigations is taken on normal operations – so called standard operating procedures during daily changing conditions and demanding situations like weather, traffic and airport related issues [6]. Contingencies and the collaboration of MPO had been investigated in a first simulator study in NICo in 2021/2022.

3 Basics

The application of SPO and MPO mainly depend on three regulatory aspects: 1. the rules for aircraft certification, 2. pilot licenses and 3. for air operations. As described before, depending on the aircraft category – aircraft are designed to be operated by one or multiple pilots - mostly two pilots. Quite a lot of normal category aircraft are certified for SPO and MPO. Large category aircraft must be operated by two pilots applying the multi crew cooperation concept (MCC) [7] and crew resource management (CRM) [8]. The MCC specifies a task division among the pilot flying (PF) and the pilot monitoring (PM) as well as quality and safety concepts like cross-checks (CC) [9]. The certification standards for normal and large aircraft affirm that normal aircraft are able being operated by a single pilot and large aircraft by two or more pilots. Accordingly, the certification covers the required equipment, accessibility and ergonomics of the cockpit respecting SPO and MPO. In the international regulatory context, normal category airplanes are also named small airplanes and large category airplanes are also called transport category airplanes.

Besides, the pilot's license specifies whether the pilot is eligible to operate an aircraft as single pilot or as part of a multi pilot crew. The commercial pilot license (CPL) permits a pilot to conduct commercial air operations as single pilot with normal category aircraft certified for SPO [7]. Pilots holding an airline transport pilot license (ATPL) are allowed to conduct commercial operations with large category aircraft under MPO. The ATPL includes the rights of the CPL, i.e. to fly normal category aircraft certified for SPO alone as single responsible pilot. Beside the roles PF and PM during multi crew cooperation, the more experienced captain is the responsible pilot for the flight, i.e. the pilot in command (PIC). The roles of PF and PM can be assigned to either the captain or the first officer and can be switched during flight.

The rules for air operations (Air Ops) extend the rules for the aircraft certification and pilot licensing. The Air Ops comprises rules for the execution of commercial air transport with normal and large category aircraft [10]. It includes for instance the requirements for the pilots and the minimum equipment depending on the operations and circumstances of the intended flight. Examples for these influencing factors are, if a flight will be conducted during night or under instrument metrological conditions, with auto land operation or in demanding surroundings like flying in mountainous regions, take-off and landing at airports with demanding procedures, or infrastructure, and more. Depending on that, the Air Ops specifies that pilots must have practiced these conditions in the recent past. Additionally, in case of conducting commercial operations with SPO certified normal category aircraft, it could also require that an operation even have to be conducted by two pilots as MPO. Due to the demanding all-weather operation of commercial air transport, in most of the cases also normal category aircraft are accompanied by a second pilot.

Prerequisite of all operational activities is that a pilot owns a type rating for the aircraft to be operated. This ensures that a pilot have the knowledge and skills to manage a certain type of aircraft in normal and degraded situations as well as being familiar to handle all the systems of the aircraft.

The challenging question is - what can be enhanced and what is needed in future commercial all-weather air transport operation to enable SPO of large airplanes as safe and reliable as MPO today? Is a remote co-pilot on demand a fill-in, or what can be handled by an intelligent assistance system?

4 Previous work

At the beginning of project, the state of the art concerning present commercial air transport was analyzed. Five domains had been considered, i.e. regulations, operation, avionics, technologies and human factors. This was followed by interviews of professional pilots and multi pilot crews in order to collect the demands concerning present daily commercial all-weather operation with large airplanes as well as challenges of future SPO with large airplanes (SPO+) [6]. 19 pilots with an ATPL or CPL were asked concerning their experiences with commercial aviation. 11 were airline pilots, 5 from military transport and fighter operations and 3 from executive charter business. 8 of them were instructors or examiner. 5 of the pilots had experiences with SPO.

The more experienced captains stated that they more or less could imagine to operate large airplanes as single pilot. In contrast, the asked first officers disagreed in SPO with large airplanes. Overall, the pilots who principally agreed to conduct SPO with large airplanes and those who disagreed were balanced. The named demands and challenges were work load and work share, decision making, contingencies, emergencies, fatigue, and pilot incapacitation amongst others.

The interviews resulted in the identification of 74 relevant aspects, events and situations. These refer to the following five areas:

1. normal operations and situations
2. demanding conditions and events
3. abnormal and problematic events and situations
4. emergency situations
5. special aspects concerning future SPO with large airplanes

Surprisingly, the interviewees gave more extensive explanations concerning normal and demanding situations than problematic and emergency situations. One reason for that might be that contingencies and emergencies represent more or less narrowed and specific situations – instead of normal operations and demanding conditions, which could vary a lot and the resulting action spans a larger field of possibilities. Hence, normal operation and demanding situations, due to weather, traffic, terrain, communication, airport or passenger related issues represent compulsory aspects that have to be treated in future SPO with large airplanes as safe and reliable as today. Accordingly, present MPO concepts and procedures have to be investigated for their implementation into enhanced intelligent assistance and automation systems as well as to provide a proper base to avoid overload, stress, overconfidence or irksome situations with too low demands. The main question to be addressed is what are the basic activities and everyday tasks in the cockpit of large airplanes?

5 Related work

Before presenting the results of published task analyses and related work, a common related base of task assignment is put in front. In principle, the conducted tasks and activities are related to the following four domains: aviate, navigate, communicate and manage aircraft systems (ANCM) [11]. These domains are quite often used to group or differ the tasks and activities when operating an aircraft. On top of these domains lays the tasks that corresponds to the mission management. Accordingly, all the activities and tasks undertaken by the pilots in the cockpit quite often refer to ANCM+M. In addition, in case of large airplanes the multi pilot crew has to respect the multi crew cooperation concept [7] and crew resource management [8]. These MPO concepts specify who is doing what and when and furthermore, the concepts add additional safety and reliability concepts like the execution of cross-checks, joint briefings, the four-eyes principle, collaborative application of checklists and decision making.

The tasks related to the execution of flights with large airplanes had been analyzed for different reasons. Friedrich et al. for instance generated and published a taxonomy for the tasks operating an Airbus A320. They investigated and discussed the possible transition from conventionally to remotely piloted airplanes and its possible impacts on the function allocation and accessibility of information [12]. The hierarchical task analysis of this work applied the so-called "Social Organization and Cooperation Analysis - Contextual Activity Template" (SOCA-CAT) [13]. The hierarchical approach comprises three layers: 1. focusing on functional purposes, abstract and generalized functions, 2. physical functions and 3. physical form. In a first step, concerning the top layer, two functional purposes were named, first the safe and second the efficient execution of a commercial flight. In a following step four abstract functions were derived which are necessary to achieve the two purposes. Each abstract function could be part of the implementation of different purposes. For instance, for a safe flight operation representing a functional purpose, the flight parameters should respect the flight envelope of the aircraft. Furthermore, it has to be ensured that the airplane will be separated from any traffic, terrain and meteorological risk and that the airplane fuel consumption and load plus the aircraft systems are properly managed. The fuel management as well as to follow the flight envelope also implements the functional purpose of conducting a flight most efficiently. In a following step, four generalized functions were identified and assigned to the abstract functions, e.g. aviate, navigate, communicate or manage aircraft systems. The four generalized functions of the first layer had been broken down to 24 physical functions, like managing speed, heading, altitude, flaps and gear as subparts of the generalized function aviate or for instance position of own ship, other traffic, terrain, meteorological effects, nav aids, airports, runways and taxiways as part of the generalized function navigate. The underlaying physical forms representing the third layer, contains the following eight items: aircraft controls and systems, aircraft performance, weather, terrain, traffic, airports and its infrastructure, Air Traffic Control Service (ATC) and airspace structure. The physical forms are the basic elements used by the physical functions. The physical functions of this hierarchical approach afterwards are used to figure out in which flight phase it is applied and by whom, i.e. the PF or the PM or the aircraft's automation, e.g. the autopilot. Hereby, the approach and landing operation of a large airplane with two pilots (MPO) were considered. Different level automation was also taken into account, i.e. flying in manual, selected or managed mode. Additionally, the used information was identified and assigned to the former physical functions. Sources of information were measured data from the aircraft and the environment. In a next step the results of the task analysis for the approach and landing with a large airplane with two pilots were taken as base for SPO. The former task distribution of the two onboard pilots has been rearranged to a single pilot and a remote pilot.

Lacabanne et al. published the results of another hierarchical task analysis [14]. This task analysis was motivated by the development of a new Flight Management System (FMS). FMS support pilots concerning flight control according to the planned route, adaptation of the route and application of flight procedures, e.g. departure, arrival, approach and landing. The flight management system represents the base for the navigation, communication with ATC and fuel management. The focus of the analysis laid on flying an airplane, i.e. ANCM. In order to identify the essential functions for the operation of the airplane, seven pilots were interviewed. One specialty was that the study regarded different types of airplanes – from normal single engine airplanes, over complex high-performance multi-engine turbine airplanes to large airplanes and even fighter jets. The task analysis comprised three level of functions and activities, one layer with related interfaces and a last layer with linked information. The first functional level contained the four domains – ANCM, the second one nine major and the third one ten subfunctions. The firstly stated functional domain navigation focused on the positioning along the flight route from start until destination. Aviate addressed manual and automated flying with respect to the envelope. The communication actions comprised the communication among the pilots as well as with ATC. Manage systems mainly contained the system monitoring regarding system and engine parameters. Furthermore, the analysis considered rough annotation of parallel and sequential task execution. The ANCM domains were regarded as parallel, i.e. that its actions were interleaved, whereas the actions of one domain follow a sequential order within each domain.

In comparison to the aforementioned hierarchical high-level task analyses, Wolter and Gore conducted a detailed cognitive task analysis in order to investigate current MPO as baseline for the evaluation of a concept for future SPO supported by a remote pilot [15]. Their concept foresees the support of the single pilot by a remote pilot or so-called ground operator in nominal operation and in case of contingencies. The regarded flight phases had been the approach and landing. A task decomposition spreadsheet was used to list all the actions by the PF, PM, automation, ATC and dispatch. The task analysis covered a nominal and an abnormal scenario, i.e. the approach and landing in Denver and a diverting due to weather conditions. These two scenarios were taken as baseline for the MPO case and for SPO with two different variants of the support by a ground operator. Based on that a workload analysis and comparison of the cases was done.

Stanton et al. applied a SOCA-CAT for MPO [16]. The specialty of this analysis is that the whole flight in general was regarded. 16 flight phases and 28 functions were considered and four potential models of SPO compared to current MPO.

6 Method

The conducted task analyses vary quite a lot concerning the applied methodology and their procedures. Some are hierarchical and abstract, some detailed, some narrowed – focusing on certain flight phases whilst others cover the complete flight or all flight phases. While task analyses for MPO has been well examined, there is the need to add further efforts in order to investigate future SPO of large airplanes. Concerning the scope of the project, the level of detail from former work and their results were not sufficient. Especially, in order to identify essential and concrete issues for the development of future robust automation and enhanced intelligent assistance, a detailed review of the basic activities and actions during a normal flight had been undertaken. This includes all inputs and outputs from the airplane systems to the two pilots – from start till shutdown.

The major difference to the former described task analyses in comparison to the high-fidelity task analysis (HFTA) is, that the conducted task analysis took a look on the basic actions in a bottom up approach. Additionally, the interfaces as well as the used information were considered. The primary goal of the HFTA is to achieve a concrete view on the work performed by the two pilots. Secondly, the analysis should provide a detailed image from the operator's perspective, how the multi crew cooperation concepts, the crew resource management and methods are implemented ensuring an as safe and reliable as possible operation. Based on, how the main actors in the cockpit jointly interact with the airplane's systems, the investigation of new task allocation and assignment towards future SPO+ by introducing enhanced assistance is started.

In the following the approach of the HFTA is depicted. The HFTA focuses on the Standard Operating Procedures (SOP) of an Airbus A320. The SOP cover all the actions to be done getting started with a cold cockpit of a parked airplane, followed by several other procedures and phases, ending with reaching the final parking position. In particular the A320 Quick Reference Handbook (QRH) comprises the following procedures [17]:

Table 1. Standard Operating Procedures (SOP) defined in the QRH [17].

#	Procedure	#	Procedure
1	Safety Exterior Inspection	12	Cruise
2	Preliminary Cockpit Preparation	13	Descent Preparation
3	Cockpit Preparation	14	Descent
4	Before Pushback or Start	15	ILS Approach
5	Engine Start	16	Non-Precision Approach (Managed)
6	After Start	17	Non-Precision Approach (Selected)
7	Taxi	18	Landing
8	Before Take-Off	19	Go around
9	Take-Off	20	After Landing
10	After Take-Off	21	Parking
11	Climb	22	Securing the Aircraft

Each procedure describes the actions of the PF and PM. The following example provides a scheme of the tabular checklist alike description of the taxi operation.

Table 2. Tabular description for taxi operation in the QRH [17].

PF		PM	
NOSE LIGHT	TAXI	TAXI CLEARANCE	OBTAIN
*** Taxi clearance obtained:**			
PARKING BRAKE	OFF	ELAPSED TIME	AS RQRD
THRUST LEVERS	AS RQRD		
BRAKES	CHECK	BRAKES PRESS	CHECK 0
FLT CTL	CHECK	FLT CTL	CHECK
		AUTO BRAKE	MAX
*** ATC clearance obtained:**			
		ATC CLEARANCE	CONFIRM
		TO DATA	CHECK
		FMGS F-PLAN/SPD	CHECK
		FCU ALT/HDG	SET
		FD	CHECK ON
FLT INST & FMA	CHECK	FLT INST & FMA	CHECK
..		..	

The HFTA contains two iterative main parts: Firstly, a common and secondly an applied perspective and analysis of the MPO tasks and actions. In the end, the approach comprises two main and two sub-iterations, i.e.:

1. the common analysis of the SOP referring to
   i. the QRH
   ii. the FCOM
2. the applied consideration of the SOPs in relation to
   i. a planned real flight
   ii. a simulation of the planned flight as MPO and SPO+

The first part concerns the detailed task analysis based on the QRH and FCOM. The briefly specified actions of the QRH had been analyzed and extended by additional information extracted from detailed description of the A320 Flight Crew Operations Manual (FCOM) [18]. The first common part represents an initial general step. The second part addresses the application of the SOP during a specific flight, e.g. from Innsbruck to Hamburg. The applied part considers a real planned flight by instantiating the common part using the data of the planned flight which additionally is going to be investigated by simulating the flight.

In the following, the content and approach of the common first part of the HFTA is described. The extracted and extended actions from the QRH and FCOM were listed in a MS Excel table. The columns of the QRH procedure description (see Table 2) were expanded for the purpose. The resulting main columns are as follows:

1. ANCM context of each action
2. pilot flying actions
3. interface, i.e. the panel and instrument, used by the PF
4. related information
5. pilot monitoring actions
6. interface, i.e. the panel and instrument, used by the PM
7. related information
8. sequential and parallel execution order
9. new action assignment to a single pilot
10. new action assignment to future assistance

Columns 2-4 and 5-7 contain derived information from the QRH and FCOM. The ANCM context of each action is generated from the action. The new assignment of the explored actions was based on educated guess. Related aspects to this were, whether the SP has to do something, e.g. due to the allocated responsibility. Furthermore, if an assistance could execute an action. This also includes the questions, whether an assistance would have access to the required information or to the interface the aircraft's subsystem. As a trivial example, the walkaround and visual inspection of the airplane so far hardly seems to be executed by an assistance. Whereby, assistance in this case means a computation or automation system, e.g. a virtual co-pilot, or a remote ground operator.

7 Results

The regarded 22 SOPs result in 463 PF actions in total, with 324 unique actions, i.e. without repetitions and the same actions with different variables. PM actions count 444 in total, with 288 unique actions. Most repeated and varied actions are announcements and orders from the PF and confirmations on the PM's side. The first two operational procedures, i.e. the safety exterior inspection and the preliminary cockpit preparation, contain 84 actions, which solely are undertaken by the PM. Both procedures mainly check aircraft systems, like the visual inspection from outside, i.e. the landing gear, doors, engines, APU area or battery, electric and hydraulic system status, and more. In parallel, the PF starts with cockpit preparation procedure. This procedure prepares the avionic systems and set up the flight management and guidance system (FMGS) by inserting the flight plan. More or less in the middle of this procedure, the detailed collaboration of PF and PM starts – "when both pilots are seated" when the walkaround and the preliminary cockpit preparation are finished.

Table 3. Beginning of the multi crew cooperation of PF and PM in the cockpit preparation procedure [17].

PF		PM	
..			
*** When both pilots are seated:**			
Glareshield (PF side):		Glareshield (PM side):	
- BARO REF	SET	- BARO REF	SET
- FD	CHECK ON	- FD	CHECK ON
..		..	
Lateral Console (PF side):		Lateral Console (PM side):	
- OXY MASK	TEST	- OXY MASK	TEST
PF Instrument Panel:		PM Instrument Panel:	
- PFD-ND brightness	ADJUST	- PFD-ND brightness	ADJUST
..		..	
- PFD-ND	CHECK	- PFD-ND	CHECK
Pedestal:		Pedestal:	
- ACP1	CHECK		
- WEATHER RADAR	SET		
..		FMGS data confirmation	
- THRUST LEVERS	IDLE	- AIRFIELD DATA	CONFIRM
- ENG MASTER	CHECK OFF	- ATC CLEARANCE	OBTAIN
- ENG MODE SEL	CHK NORM	- IRS ALIGN	CHECK

- PARKING BRAKE PRESS	CHECK	..	
..		- F-PLN A and B	CHECK
- ATC	SET		
- FUEL QTY	CHECK	- ATC CODE	SET
		- FUEL QTY	CHECK
- TAKEOFF BRIEFING	PERFORM		

The cockpit preparation procedure shows parallel and duplicated actions of PF and PM, e.g. setting the barometer parameter, enabling the flight director (FD) and checking the oxygen masks (see Table 3). Due to the fact that the captain (CPT) and the first officer (FO) can take the role of PF and PM, some instruments, controls and input units are doubled in the cockpit, i.e. on the left and the right side of the cockpit. Other controls, like levers for the thrust, flaps, speed brakes, landing gear, and more have only one instance in the cockpit, but all are reachable from both seats with restrictions for the landing gear lever. The cockpit preparation procedure depicted in Table 3 also shows parallel, independent actions. This is the case for the confirmation of the airfield data, obtaining the start-up clearance from ATC, checking the IRS alignment and flight plan (F-PLN) by the PM. Thereafter follows a re-synchronization in order to set and cross-check the ATC code and fuel quantity.

Regarding the ANCM assignment and context of the actions in Table 4, the mix of actions concerning the four domains as well as the work share between the PF and PM can be seen. Further, the actions of the four domains sometimes are independent and sometimes there is a relation and dependency, causing a sequential order of actions of different domains.

Table 4. Parallel and independent actions of ANCM tasks on the example of the cockpit preparation procedure.

PF	ANCM	PM	ANCM
..			
		<u>FMGS data confirmation</u>	
- THRUST LEVERS CHECK IDLE	Aviate	- AIRFIELD DATA CONFIRM	Manage
- ENG MASTER CHECK OFF	Aviate	- ATC CLEARANCE OBTAIN	Communicate
- ENG MODE SEL CHECK NORM	Aviate	- IRS ALIGN CHECK	Navigate
- PARKING BRAKE PRESS CHECK	Aviate	- GROSS WEIGHT INSERTION CHECK	Manage
..		- TO DATA CALCULATE/CHECK	
- ACP2 CHECK	Communicate	- F-PLN A and B CHECK	Manage
- ATC SET	Communicate		

- FUEL QTY CHECK	Manage	- ATC CODE SET	Communicate
		- FUEL QTY CHECK	Manage
- TAKEOFF BRIEFING PERFORM	-		-

Apart, in the take-off procedure – actions of the same domain, i.e. aviate, are jointly executed by the PF and the PM. As shown in Table 5 the PF commands "Gear up", "Flaps1" and "Flaps 0". The PM executes his commands and confirms the execution. In case of changing the configuration when setting the flaps, the PM also checks the current speed and related constraints for the new flaps setting. This is one part of cross- and double-check concerning the execution of essential actions and changes. This implements a four-eyes principle as safety and reliability function.

Table 5. Collaboration of PF and PM concerning aviate actions on the example of the take-off procedure.

PF	ANCM	PM	ANCM
..			
*** WHEN V/S is positive:**		- ANNOUNCE "POS CLIMB"	Aviate
- ORDER "GEAR UP"	Aviate	- LANDING GEAR UP	Aviate
		- GRND SPLRS DISARM	Aviate
		..	
- A/P AS REQUIRED	Aviate	- ANNOUNCE "L/G UP"	Aviate
- ANNOUNCE FMA	Aviate		
*** At thrust reduction ALT:**	Aviate	- ONE PACK ON	Manage
- THRUST LEVERS CL	Aviate		
- ANNOUNCE FMA	Aviate		
*** At acceleration ALT:**			
- ANNOUNCE FMA	Aviate		
*** At F speed:**	Aviate		
- ORDER "FLAPS 1"	Aviate	- FLAPS 1 SELECT	Aviate
		- CONFIRM/ANNOUNCE "FLAPS 1"	Aviate
*** At S speed:**	Aviate		
- ORDER "FLAPS 0"	Aviate	- FLAPS 0 SELECT	Aviate
		- CONFIRM/ANNOUNCE "FLAPS 1"	Aviate
		- 2ND PACK - ON	Manage

When re-assigning the PF and PM's actions to a single pilot (SP) and an assistance system or support by a remote pilot (AS), the essential question is, if the assistance has access to the system interfaces and the right information in order to be applied. Furthermore, fundamental aspects, like the responsibility or the decision making, are fixed to the single pilot's side. Table 6 demonstrates a possible re-assignment on the example of the cockpit preparation procedure. Many actions previously performed by the PF and the PM, might be shifted into an assistance system – provided that there is a proper access the system using the same or additional interfaces, and it has access to the controls. Checking does not only mean to evaluate the position of a switch or lever, it also includes if the evaluation result is not as it should be, to achieve the right position. Other actions have to be executed by the SP and AS together. For instance, obtaining the ATC clearance likely might be triggered by the SP. However, the result of requesting the startup clearance must be forwarded from the AS to the SP. Another example is the calculation and check of the take of data. The first is done by the FMGS, but the check and validation should be accomplished by the SP.

Table 6. Re-assignment of PF and PM actions to a single pilot (SP) supported by new enhanced assistance system (AS) on the example of the cockpit preparation procedure.

PF	SP/AS	PM	SP/AS
..			
		FMGS data confirmation	SP/AS
- THRUST LEVERS CHECK IDLE	AS	- AIRFIELD DATA CONFIRM	AS
- ENG MASTER CHECK OFF	AS	- ATC CLEARANCE OBTAIN	SP/AS
- ENG MODE SEL CHECK NORM	AS	- IRS ALIGN CHECK	AS
- PARKING BRAKE PRESS CHECK	AS	- GROSS WEIGHT INSERTION CHECK	AS
..		- TO DATA CALCULATE/CHECK	SP/AS
- ACP2 CHECK	AS	- F-PLN A and B CHECK	AS
- ATC SET	SP/AS		
- FUEL QTY CHECK	AS	- ATC CODE SET	SP/AS
		- FUEL QTY CHECK	AS
- TAKEOFF BRIEFING PERFORM	SP		

Apart from that, in the take-off procedure – today, aviate actions are jointly executed by the PF and PM. This results in a proper implementation of the collaboration between the SP and AS. Proper in this case means, that the assistance can provide alerts in case of deviations from given constraints, but including the possibility to overrule this and forcing the application of an order of the single pilot, like it can be the case of the pilot in command in case of MPO, for given reasons. Another aspect is, that the situational awareness is cross-checked when the flight mode annunciator (FMA) state changed and the SP will make a callout. An assistance system must check it semantically according to the system state and situation. Hence, FMA announcements must be properly implemented and performed by the SP and AS. Additionally, ATC code settings and changes should be announced to the SP when assigned to the assistance system. This requires further changes concerning the integration and interconnection of future aircraft systems.

Table 7. Re-assignment of PF and PM actions to a single pilot supported by new enhanced assistance system on the example of the take-off procedure.

PF	SP/AS	PM	SP/AS
..			
*** WHEN V/S is positive:**	-	- ANNOUNCE “POSITIVE CLIMB”	AS
- ORDER “GEAR UP”	SP/AS	- LANDING GEAR UP	AS
		- GRND SPLRS DISARM	AS
		..	
- A/P AS REQUIRED	SP	- ANNOUNCE “L/G UP”	AS
- ANNOUNCE FMA	SP/AS		
*** At thrust reduction ALT:**	-	- ONE PACK ON	AS
- THRUST LEVERS CL	SP/AS		
- ANNOUNCE FMA			
*** At acceleration ALT:**	-		
- ANNOUNCE FMA			
*** At F speed:**	-		
- ORDER “FLAPS 1”	SP/AS	- FLAPS 1 SELECT	AS
		- CONFIRM/ANNOUNCE “FLAPS 1”	AS
*** At S speed:**	-		
- ORDER “FLAPS 0”	SP/AS	- FLAPS 0 SELECT	AS
		- CONFIRM/ANNOUNCE “FLAPS 1”	AS
		- 2ND PACK - ON	AS

8 Discussion

None of the actions undertaken to operate a large airplane can be omitted. As figured out before, they have to be evaluated concerning their re-assignment, i.e. to the single pilot or an onboard or remote assistance. The task distribution of the PF and PM or better their multi crew cooperation results in independent and sequential actions according to the task in a given procedure. The multi crew cooperation comprises a task share, cross-checks and the four-eyes principle.

One essential point for the assignment of an action is the feasibility to have access the system interfaces, i.e. controls and panels, and to have access to the needed information, e.g. checking the airplane condition by walking around. As one outcome of the conducted HFTA, the potential developments and adaptations of the human machine interface in the cockpit seems to cause also changes of the airplane system interfaces enabling an onboard assistance to access the controls and required information. A remote assistance would also need additional interfaces. However, it is more likely, that an additional enhanced onboard assistance system will support a single pilot in large airplane in future. Two aspects are crucial concerning the additional interfaces. First, the fact, that the actions assigned to a new assistance somehow implements a multi crew cooperation. This means, that the needed interfaces must fit to the airplane systems as well as to the remaining single pilot. Otherwise, actions of the multi crew cooperation will be separated and as result the new action assignment will not represent the former multi crew cooperation. The second point is, that the additionally given access to the assistance system, which is equal or similar to access of the PF and PM (see Table 6), represent a crucial safety case. As previously stated, the PF gives orders to control the landing gear, flaps, speed brakes, and so on. The controls should be accessible or at least readable by the assistance in order to implement the cross-check while the single pilot as responsible pilot in command must always have the ability to overrule any assistance system. Otherwise, if the access is not provided, a lot of actions will be added to the actions a single pilot has to perform. This might cause additional work and prolongs processes in the case when these actions could be done in parallel, e.g. in the cockpit preparation procedure (see Table 6).

Beside the accessibility aspect, the detailed view on the actions and how safety and reliability features like cross-checks are implemented showed, that a re-assignment solely focusing on the ANCM context of an action does not enable necessary developments and adaptations of future cockpits (see Table 5 and Table 7).

Another aspect concerns the communication. A transferred allocation of the communication to an assistance system must be synchronized with the single pilot. This could concern the initiation of a communication on the one hand and on the other hand providing the result and content of the communication properly, e.g. the communication with the ground staff during push back, or startup clearance or taxi information. At present, systems like Aircraft Communications Addressing and Reporting System (ACARS) and Controller Pilot Data Link Communications (CPDLC) going in the right direction. Despite this, that communication systems have to be properly implemented and integrated – they also have to be provided by the ATC service, resulting in environmental efforts and network constraints concerning its availability.

A further crucial aspect represents the cross-check of the situational awareness. The announcements of the flight mode, represent an essential part of checking the mode awareness of the pilot flying by the pilot monitoring. This has to covered by an assistance as well.

Overall, in situations where the single pilot acts as PF all the other assisted actions must be properly implemented in order to support the single pilot and not causing additional efforts to the SP - especially, when flying manually using the flight director or when operating on ground. In contrast, the autopilot system has to be more robust in order to support the SP as much as possible, so that the SP will not be forced taking over manual flying activities including in case of contingencies.

9 Conclusion

The contribution introduced the basics of current commercial aviation by differentiating normal from large category airplanes, the pilot licensing and multi pilot from single pilot operation. The institutional funded project NICo and preceding work briefly were described. Related work concerning published task analyses is reviewed. Furthermore, the approach of the conducted high-fidelity task analysis is presented and the results discussed. The analysis showed, how the multi crew cooperation and other involved concepts like task share, cross-checks and the four-eyes principle are implemented in current MPO. The re-assignment of activities and actions performed by the pilot flying and pilot monitoring to a single pilot onboard and a supporting assistance system showed, that the implemented concepts will have to be dealt with care when implemented in future systems. The focus on the SOPs, beginning from startup until shutting down the airplane, purposely was chosen in order to investigate needs and challenges in normal operation as seeding point and basis for further investigations. Aspects like crew incapacitation, the management of contingencies and emergency situations are subject of other work packages within NICo. Hence, the requirements for single pilot operation with large airplanes, e.g. enhanced assistance and automation functions, shared control and shared situational awareness, had been initially regarded in this work when shifting and re-implementing concrete actions from the second pilot to a single pilot or an assistance system. Hereby, the accessibility of interfaces and used information plays a key role, especially when the support comes from a remote pilot on ground. The HFTA permitted detailed insights. In a next step, the results of the HFTA will be applied to a complete planned flight with an A320. The instantiation of the SOPs for this flight are going to be examined using the flight planning data and a simulation. Further investigation concerning the feasibility of the transition from MPO to SPO with large airplane will be made herewith. Apart from the actions of SOPs, the consideration and simulation of planned flight will regard additional tasks, e.g. the mission management, observing the mission progress and environmental conditions as well as the decision-making process when occasions causes changes of the route or destination.

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