Flight Crew Coordination in Mixed Reality: The Effects of Using Video Passthrough for Vision

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Abstract

Head-mounted mixed reality devices are making their way into airline pilot training. Devices that use passthrough video hold much promise but come with caveats. Because current generation passthrough video devices occlude natural light, users rely entirely on a digital video feed that lacks the visual fidelity and field of view of the unaided human eye. The application of head-mounted extended reality devices in aviation has been predominantly examined in single-pilot contexts, with limited attention given to their implications for multi-crew flight decks. This study explored the effects of using a mixed reality device incorporating passthrough video in the context of a multi-crew airline operation, i.e., two co-located users wearing a head-mounted device, engaged in joint activity. The perspective taken was crew coordination.

The methodology was inspired by an exploratory multiple case study research design. A naturalistic setting was achieved with experienced professional pilots flying a high-fidelity simulator in realistic scenarios. Multiple crews flew two similar scenarios, one with the head-mounted device and the other without it. The activity was observed and recorded for later analysis, and the crews were interviewed post-session about their experiences. Findings suggest that the technology is not value neutral and alters how the crew coordinates their work on a flight deck. The device disrupted normal work rhythm, created additional workload and affected how often the pilots looked at each other. These effects should be explored further and considered when designing training programs for pilots in multi-crew environments using mixed reality devices.

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Abbreviations

AR – Augmented reality
BITD – Basic instrument training device
CRM – Crew resource management
CSE – Cognitive systems engineering
EASA – European Aviation Safety Agency
EBT – Evidence based training
FMS – Flight management system
FOV – Field of view
FTD – Flight training device
FFS – Full flight simulator
FNPT – Flight and navigation procedures trainer
HUD – Head-up display
JCS – Joint cognitive system
MR – Mixed reality
PF – Pilot flying
PM – Pilot monitoring
Q3 – Meta Quest 3
SOP – Standard operating procedures
VR – Virtual reality
XR – Extended reality

Flight crew coordination in mixed reality: the effects of using video passthrough for vision

This research is about bringing a head-mounted mixed reality (MR) device with passthrough vision to an airliner flight deck, where an experienced flight crew explores the implications of using such a device in their normal work. In practice this is carried out in a full flight simulator (FFS), where several crews fly purpose designed scenarios with and without the headset. They are observed flying the scenarios and later are interviewed about their experiences.

Simulators in flight training

Contemporary airline pilot flight training is conducted mostly in simulators, which have various levels of fidelity. Aviation regulators have certification specifications for different levels of simulation fidelity used in pilot training. In the European Union, EASA defines 4 main categories of simulators: full flight simulators (FFS), flight training devices (FTD), flight navigation procedures trainers (FNPT) and basic instrument training devices (BITD) (EASA CS-FSTD(A), 2018). The authority also defines the needed level of simulation used for different types of mandatory training, e.g., the biannual recurrent airline pilot training must be given in an FFS (EASA Part FCL, 2023). The FFS includes a motion system and it has the highest level of fidelity relative to the aircraft it is simulating. This also makes the procurement and operation of these types of simulators most expensive.

A simplified way of looking at pilot flight training is by dividing it into two: training for inexperienced pilots and training for experienced crews. Here, training inexperienced pilots means training those who are not familiar with the aircraft, (e.g., type rating) and/or those who are new to the company, meaning they are training procedures new to them. This type of training is often called initial training. Usually with this category of training syllabi, there is a progression from training simple and basic things independently, to doing more complex work as a crew. The simpler things can be done with computer-based training or with low-fidelity simulators such as the FNPT, while training as a crew usually takes place in high-fidelity FFS.

Experienced pilots are mostly trained as crews in what is called recurrent training, usually taking place at least biannually. The contemporary way of conducting recurrent training is exposing the crews to various realistic scenarios and situations in an FFS and in this way train their more generic competencies, such as workload management and decision making (ICAO EBT, 2013). This current training paradigm

called 'Evidence-Based Training' or EBT, tries to train pilots in scenarios that resemble realistic line flying operations. There is research suggesting that the environment would not necessarily need to be high-fidelity to be able to train generic team skills (e.g., Dahlstrom et al., 2009; Hamstra et al., 2014; Massoth et al., 2019; Salas et al., 1998). However, this sort of low-fidelity training for experienced crews seems to be uncommon in airlines, maybe because of the regulated nature of pilot training and the costs involved in arranging additional training for crews outside of the regulated minimum requirements.

With the high costs of FFS operations, airlines are exploring cost-effective training alternatives. If the same thing can be trained just as well in a cheaper low-fidelity simulator, then the expensive high-fidelity simulator capacity can be used for something else or sold to third parties. However, rather than fully replacing FFS training, it seems more plausible that cheaper lower fidelity devices using new technologies could be used as a complement, where some training elements from an FFS are offloaded to these more cost-effective setups. One interesting area of technological progress for future pilot training is extended reality (XR). The author's current employer, Finnair, is taking part in a government funded project to explore the feasibility of using mixed reality (MR) devices in pilot training. Although this thesis is not directly a part of the project, it provided an avenue of collaboration to produce mutually beneficial work using shared resources and interests. Crucial benefits of this collaboration included the access to an FFS and being able to use various MR devices.

Extended reality

What does extended reality (XR) mean? In popular media, the use of terminology can often be confusing, but XR is basically an umbrella term used for brevity. It contains virtual reality (VR), mixed reality (MR) and augmented reality (AR) technologies. While one could dive deep into the centuries old discussion about what reality is or look at a more sophisticated contemporary version of the reality-virtuality continuum (e.g., Skarbez et al., 2021), Milgram & Kishino (1994) provide simpler definitions that will suffice here. According to Milgram & Kishino, MR involves "the merging of real and virtual worlds somewhere along the 'virtuality continuum' which connects completely real environments to completely virtual ones" (p. 2).

The interest of this paper lies in head-worn MR devices (as opposed to, e.g., hand-held devices), also sometimes referred to as MR headsets. One relevant technical aspect of these devices is the choice of

how they display the world and the virtual content in the visual field of the user. These displays can be divided into two main categories: optical see-through and video passthrough. In optical see-through content is projected onto a transparent lens, while still allowing the user to see the light from the physical world. In video passthrough devices the user is unable to see natural light and must solely rely on real-time digital video of the world (Bailenson et al, 2024).

The idea of augmenting the visual field of the pilot with extended reality is not new. In military aviation, various optical see-through displays have already been in use for decades, either on the aircraft glareshield as a head-up-display (HUD) or integrated straight into the visor of the helmet of a pilot (Rash & Martin, 1988). Also primarily used in the military, an early example of a head-worn passthrough video device is the night vision goggle. However, these military applications are used to aid the pilot by bringing operationally relevant information, such as flight instrument or weapon data, to the visual field, not so much as a primary training device. In contrast, latest commercially available XR devices can be used in quite flexible ways to train pilots and create training environments, e.g., classroom training, flight deck procedure training, aircraft preflight outside inspection training, airport familiarization, etc. (Schaffernak et al., 2022).

There are some fundamental differences in the technological capability between optical see-through and video passthrough devices, at least for the foreseeable future. Before 2020's, most commercially available AR and MR devices used optical see-through displays, notable examples being the Microsoft HoloLens (2016), Magic Leap (2018) or even Google Glass (2014) (Bailenson et al., 2024). Optical see-through displays have several technological challenges which limit their potential use cases. These include a small field of view for digital content (Doughty et al., 2022), altered colour perception due to mixing of digital rendered content with ambient light (Kruijff et al., 2010), difficulty of seamlessly combining real and virtual content, and the inability to delete (or mask) large areas of the world (Bailenson et al., 2024; see also Cheng et al., 2022, for more on 'diminished reality').

In addition to optical see-through displays, we have seen technology companies starting to bring out devices incorporating video passthrough in the past decade or so. The consumer market has seen influential Silicon Valley technology companies Apple and Meta bring out their MR headsets with the Apple Vision Pro (2024) and the Meta Quest 3 (2023), both with video passthrough. On the industrial

side of the market, the Finnish company Varjo has launched the XR-3 (2020) and more recently the XR-4 (2024). Video passthrough enables better integration of real and virtual information, because both are digital and can be combined at the pixel level (Bailenson et al., 2024). Contemporary video passthrough also enables a better field of view (FOV) for virtual content, e.g., the XR-4 displaying 120 degrees in the horizontal and 105 degrees in the vertical (Varjo Official Website, 2024), and the Quest 3 having 110 degrees and 96 degrees, in the same respect (Oliver, 2023).

Mixed reality in pilot training

The ability to better mix real and virtual environments in video passthrough has airlines interested in the technology and its potential to create novel cost-effective ways of training pilots (Schaffernak et al., 2022). Pure VR can be a good way of giving initial training to pilots who are new to an aircraft, i.e., type rating training. For example, the trainee can take the standalone headset home and get acquainted with the flight deck controls and procedures in a realistic virtual environment, instead of just reading text and looking at pictures of it. While VR offers many use cases, it also has its limitations, such as lack of haptics. Pressing virtual buttons does not give you the physical feeling of pushing a button, lowering the fidelity of the experience. MR devices offer the option to mix real physical environments (such as flight decks with buttons) with virtual elements (such as the view outside the aircraft) giving more flexibility in designing training setups and syllabi. Also, as mentioned earlier, most of the flight training in airlines involves training as a crew. This creates challenges for using XR devices: how do you represent the other crew member(s) in a full or mixed virtual reality environment? While full VR can provide virtual avatars for multi-user participation, MR offers the possibility to actually see the person you're next to, albeit with the XR device obscuring some of their natural facial cues. An example of a training environment in MR could be a replica of the flight deck physical space, but where the software, aircraft displays, and the outside visual environment is created virtually in the MR headset. This way the fidelity of the tactile physical space (including the other crew member) would be kept high, while creating other elements virtually could enable cost-savings or even completely novel ways of doing flight training.

Novel ways of training and the design of virtual elements might mostly be a problem to be solved with good imagination and enough processing power, but there are some physical realities that can't be easily reconciled with the current generation of head-worn MR technology that uses passthrough vision.

For instance, it is no surprise that human natural vision is still far superior to passthrough video in many respects (Li et al., 2022a) and relying solely on digitally produced video for looking at your surroundings, with no natural light hitting the eye, has its drawbacks. One of these drawbacks is that the device using video passthrough usually blocks the rest of the peripheral vision of the user beyond the actual display, effectively reducing the FOV of the user. Also, when compared to normal human vision, contemporary passthrough video has inferior visual acuity, dynamic range, and latency, while also having distortions of colours, lighting, shapes and sizes (Bailenson et al., 2024). Obviously, the magnitude of the distortions varies from device to device, but as Bailenson et al. point out, these discrepancies can affect essential skills such as distance estimation (Gagnon et al., 2020; Vaziri et al., 2017) and hand-eye coordination (Park et al., 2008; Lee et al., 2013), while also possibly leading to simulator sickness (Moss et al., 2011; Kim et al., 2014).

Research focus

Given the above constraints, this study focuses on the visual experience of passthrough video and its impact on flight deck work. Successfully operating an airliner requires a significant amount of coordination from the flight crew (Hutchins, 1995b). This coordination can be both very subtle and also explicitly overt. As Klein et al. (2005) write, it can be seen as a choreography. Introducing passthrough video into this dynamic environment may influence subtle and overt aspects of teamwork and it should thus be visible in the choreography of coordination that the crew exhibits in operating the aircraft. Thus, the scientific object of interest in this study is *crew coordination*.

In this study, overlaid virtual elements were omitted to keep the scope of the research within prescribed boundaries and to better keep the focus on the above-mentioned effects of passthrough video. However, it is argued that the research will be relevant to also those cases, where there would be virtual elements added. This is because the overlaid virtual elements would be added on top of the more physical effects already present (i.e., reduced FOV & visual distortions). And although the resulting effects might not be exactly the same, the addition of virtual elements would not wholly negate their existence.

Literature review

This study can be seen as situated in the intersection of pilot training, XR technology and human factors, which gives it a large interdisciplinary literature base. In this literature review it is attempted to touch on some of the relevant aspects of each.

CRM and EBT

In the 1970s, pilot training began to evolve from focusing solely on 'stick-and-rudder' skills to adopting a more comprehensive approach that also incorporated team and managerial aspects of flight operations into training programmes. Initially, this was called cockpit resource management, but later evolved to crew resource management or CRM (Kanki et al., 2019). The first CRM courses began to emerge in the early 1980's and since then have been a staple of pilot training, even being a mandatory part of getting a pilot's license (EASA, 2023). The content of CRM training covers various 'soft skills', such as leadership, teamwork, communication, and decision making (Kanki et al., 2019). There has been extensive academic research conducted on the subject over several decades, particularly by the University of Texas research group under the leadership of Robert Helmreich (see Kanki et al., 2019, for an overview).

A more recent effort to study flight deck environments and flight training is the evidence-based training (EBT) program, where various stakeholders from the industry and academia came together to overhaul how airline pilot training should be conducted in the future (ICAO, 2013). The EBT working group studied flight operations and flight training from various aspects and produced a list of 'core competencies' for pilots, that should be the focus of training in the future (IATA, 2013). These core competencies are not too dissimilar in nature to the contents of established CRM programs, but nevertheless present a divergent path for pilot training. The core competencies defined by ICAO are application of procedures, communication, aircraft flight path management, leadership and teamwork, problem solving and decision making, situation awareness, and workload management (ICAO, 2013). The participant crews used in this research were all familiar with the core competencies defined in EBT, because their employer had implemented the concept in its pilot training program some years earlier. These core competencies were used in the interview parts of this research as conversational anchors to elicit detailed experiences out of the participants.

Coordination

The study of crew coordination in this research makes use of the work done by Klein et al. (2005) paper 'Common ground and coordination in joint activity'. In their work they outline key aspects of team coordination, including the criteria for joint activity, requirements for joint activity and the choreography of joint activity. Interesting for this research in particular is the choreography of joint activity that entails the concepts of phases, signalling, coordination devices and coordination costs (Klein et al., 2005, p. 143). These concepts were used when formulating the theoretical propositions and protocol questions for the data collection and analysis phases of this study.

According to Klein et al. (2005), *a phase* is a joint action with an entry, a body of action, and an exit. Coordination is accomplished one phase at a time in a joint activity, although there may also be other embedded joint actions within any joint action (p. 150). Participants in a joint activity need to *signal* each other about transitions within and between phases, while additionally they may need to signal other matters as well, such as their intentions or any difficulties they are experiencing (Klein et al., 2005, pp. 151-152). Signalling also means directing the attention of other participants to signals, or to use signals to direct their attention to relevant cues in the situation. *Coordination devices* (Klein et al., 2005, p. 153) permeate through the choreography of joint activity. Klein et al. list typical examples of coordination devices: agreement, convention, precedent, and situational salience. In the context of flight deck work, an example of an important coordination device is the flight crew operating manual and its standard operating procedures (SOP). Procedures, task sharing, roles and standard callouts all prescribe the work-as-imagined guiding the flight crews' almost every action.

Another very central concept to this research is the *costs of coordination*. "Fundamental to coordination is the willingness to do additional work and to narrowly downplay one's immediate goals in order to contribute to the joint activity" (Klein et al., 2005, p. 156). Klein et al. (2005, p. 156), referencing Schaeffer (1997) and Klinger & Klein (1999), identify various types of coordination costs associated with joint activity.:

> "Synchronization overhead (time wasted in waiting for one entity to complete its work before the next one can begin); communication overhead (effort to manage the handoff); redirection overhead (wasted time and energy in going in the wrong direction after a new direction is called

out but before all entities can be told to change course); and diagnosis overhead (the additional burden of diagnosing a performance problem when multiple moving parts are involved)."

These four concepts enable the study of a flight deck team at work, particularly in observing how the introduction of an external artefact, such as a head-mounted XR device, may influence their coordination of tasks.

An important concept related to joint activity is common ground (Klein et al., 2005, p. 146). Common ground refers to a team's mutual beliefs, assumptions and knowledge that support independent actions in joint activity. Crucially, it permits the participants to use abbreviated forms of communication and makes it possible to understand possibly ambiguous messages. Klein et al. describe common ground as a process of communicating, testing, updating and repairing mutual understandings. The degree of quality of common ground demanded by the participants can vary depending on context. An approach briefing can be seen as an example of a coordination device that supports common ground. During a more relaxed phase of flight, the crew engages in planning and goes through the steps required and expected during the approach. Both crew members get to chime in and express their viewpoints on various matters. Roles and task sharing is briefed. After the briefing, both pilots should have an idea of what is to follow and crucially, they both know that the other pilot has the same knowledge as they have. When the actual approach with higher workload is taking place, the crew can be more efficient and effective, because they don't need to discuss or arrange for matters anymore, they're just executing the plan.

Joint cognitive systems

Bringing new artefacts to a work environment is not trivial. Hollnagel & Dekker (2024, p. 8) warn against the use of substitution principle, where the common assumption is that "artefacts are neutral in their effects and that their introduction into a system therefore only has intended and no unintended consequences." This assumption would only work in our case if the artefact would not interact with the system, which is clearly not the case with a device that makes the user 'see the world through a digital prism' (Bailenson et al., 2024). This research draws from the core values of cognitive systems engineering (CSE) and its study of joint cognitive systems (JCS). CSE tries to capture how the strategies and behaviour of people are adapted to the constraints and demands of fields of practice (Woods & Hollnagel, 2006, p.

4). A JCS is defined as a system where human and technological elements interact in a collaborative and adaptive way to solve problems, with cognition distributed across both the people and the tools they use (Hollnagel & Woods, 2005). It is about human-machine co-agency, instead of human-machine interaction (p. 42). To study a JCS is about trying to understand how artefacts shape cognition and collaboration in a work context, and how individuals and teams shape artefacts to meet the demands of the work activity, and how they cope under the pressures of organizational demands and resource constraints (Woods & Hollnagel, 2006, p 5). This research studies airline crews in a naturalistic work context, while introducing a new artefact (i.e., the MR headset) into the JCS. The new artefact creates new constraints, demands and affordances, and the JCS must adapt in how it gets the work done. The aim of this research is to capture the "stories of coordination or miscoordination, stories of resilience or brittleness, stories of support or clumsiness from artefacts." (Woods & Hollnagel, 2006, p. 9).

When observing cognition shared across people and artefacts, the work of Edwin Hutchins also becomes relevant (Hutchins, 1995a). An influential paper from Hutchins (1995b) looked at crew coordination on a flight deck from the perspective of distributed cognition, where cognition is not just internal to the brain but extends to external systems, such as artefacts. In the 1995 paper 'How a cockpit remembers its speeds', his framework is concerned with how information is represented and how representations are transformed and propagated in the performance of tasks, and the unit of analysis for the cognitive system is the cockpit as a whole. Hutchins' framework further feeds into the analysis of the choreography of coordination mentioned earlier (Klein et al., 2005). Observing the minutiae of phases and signalling, especially through use of artefacts, enables richer analysis of the JCS coordinating its work. Coordination devices, such as checklists and briefing templates, are artefacts that interact with the new artefact (the MR headset), and the JCS must adapt how it transforms and propagates information through these various coordination devices found on the flight deck.

Schema theory

Using subject matter experts as your informants and trying to replicate a naturalistic work setting means that previous experience, knowledge and skill will play an important role in the study. Schema theory suggests that knowledge is stored as structured mental frameworks that guide perception, memory, and behaviour (Graesser & Nakamura, 1982; Mandler, 1984; Plant & Stanton, 2012b). These schemata are

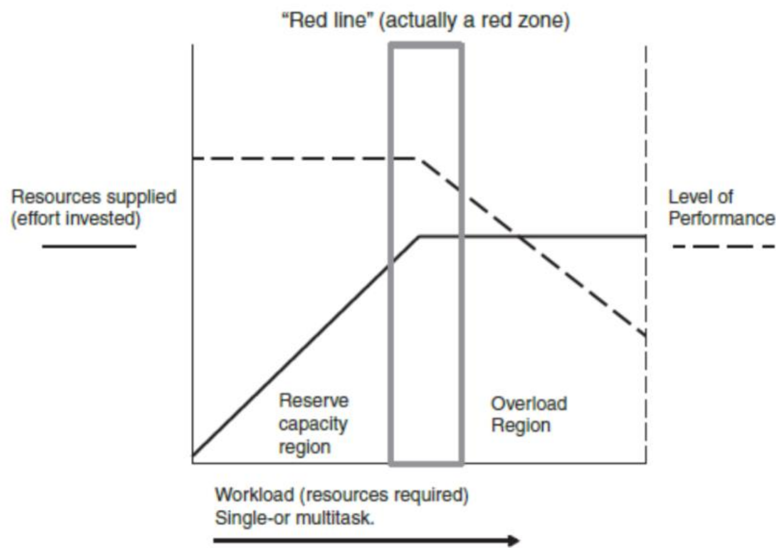
metaphorical networks of associated concepts, representing generalized knowledge across similar situations (Plant & Stanton, 2012b). When a person carries out a task, schemata affect and direct how they perceive information in the world, how this information is stored and then activated to provide them with past experiences and the knowledge about the actions required for a specific task (Neisser 1976). The nature of flight deck work is very standardized and in scheduled airline operations events are usually relatively regular and repetitive across different flights. Repetition creates anticipation and strong schemata. Arguably, if asked, most pilots could probably describe their 'normal day' at work and the sequence of events in great detail from start to finish. In a singular study like this one, the standardized way of working is probably very resistant to change and outside influence, e.g., when using a headset with passthrough vision.

Workload and the Bedford scale

During the initial part of the data collection phase, it became apparent that it might be of value to gather data on workload to complement the other sources of evidence. Workload can be defined as the relationship between the resources required to carry out a task and the resources available to, and hence supplied by, the person carrying out the task (Wickens & Tsang, 2015). In Figure 1, Wickens & Tsang (2015) present a graphical supply-demand model of workload. The x-axis shows task demands; the y-axis shows available resources (solid line) and observed performance level (dashed line). As demand increases, resources meet it until a limit is reached, beyond which performance declines due to insufficient resources. Left of the red line is a region of residual resources and to the right is the region of workload overload. For this study, it is important to differentiate between the concepts of data limits and resource limits relating to workload. Norman and Bobrow (1975) describe data limits as those that are due to missing data, e.g., inadequate lighting making it hard to see relevant data or excessive noise that makes hearing signals difficult. In contrast, resource limits are related to the mental workload that is the target of measurement in this study (Wickens & Tsang, 2015). A very low resolution passthrough video could create workload in the form of data limits: the pilot just cannot see details (e.g., text on displays) clearly enough. As will be elaborated on later in the discussion section, it can be difficult to differentiate the effects of data limits and resource limits on the experienced workload measures, especially subjective ones.

Figure 1

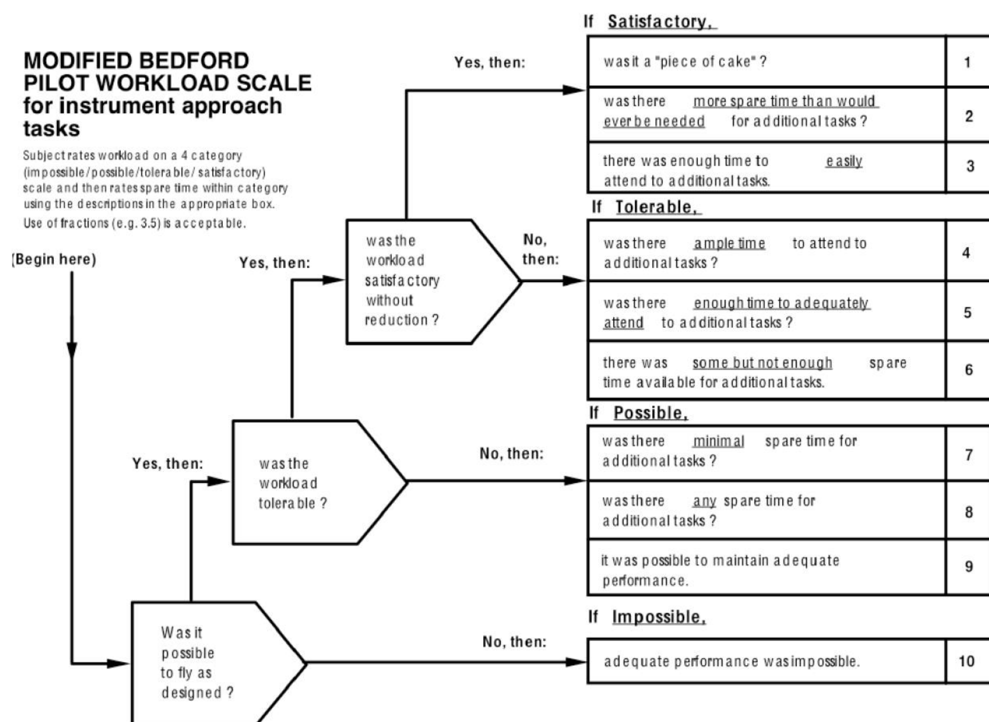
The concept of the red line, illustrating the two regions of workload (Wickens & Tsang, 2015)



Casner & Gore (2010) present a modified Bedford pilot workload scale for instrument approach tasks (see Figure 2), which is based on an original by Roscoe (1984). The Bedford Workload Scale collects subjective workload ratings using a 10-point scale with detailed verbal descriptions. It simplifies selection through a hierarchical decision tree, guiding users to a few options before choosing a final rating.

Figure 2

Modified Bedford workload scale (Casner & Gore, 2010)



Extended reality technology

Looking at the technology itself, extended reality devices have enjoyed the attention of researchers in a multitude of disciplines. One of the more common topics relating to research on head-mounted XR display technologies, is their effect on human performance (e.g., Bailenson et al., 2024). Errors in distance estimation (Gagnon et al., 2020; Vaziri et al., 2017; Creem-Regehr et al., 2023; Kelly, 2023), effects of visual distortion in passthrough environments (Lee et al., 2013; Lee & Park, 2020) and simulator sickness (Moss et al., 2011; Kim et al., 2014; Saredakis et al., 2020) are all well-known and researched areas of interest. All these become very relevant, when bringing this technology inside a flight deck.

In aviation, XR technology has been studied in training pilots, maintenance operations, aircraft design and air traffic control (e.g., Kaplan et al., 2021; Eschen et al., 2018; Joyce & Robinson, 2019; Schaffernak et al., 2022; Liu et al., 2020). Outside of aviation, research of XR use in collaborative environments is plentiful. Topics include remote collaboration (e.g., Gupta et al., 2016); remote support settings for e.g., construction tasks (Fakourfar et al., 2016; Johnson et al., 2015); interaction with shared

3D objects among co-located users (e.g., Müller et al., 2016); and awareness mechanism, such as gaze cues and pointing (Deza et al., 2017; Yao et al., 2018; Kytö et al., 2018). Contrasting previous research, Prilla (2019) studied coordination in short-term synchronous cooperative mixed reality and found that less communication and coordination gave best results, and that virtual awareness cues were not used for most of the task.

A defining feature that is interesting for this research is that the collaborators are co-located in the same space. Here different ways of communicating are key, and as Kiyokawa et al. (2002) found, a wide variety of verbal and non-verbal communication cues are used to establish shared understanding. They also note in their research that "generally, the more difficult it was to use non-verbal communication cues [in collaborative MR environments], the more people resorted to speech cues to compensate" (p. 1). Another relevant aspect is the location of the task space. On a flight deck, the pilots sit side-by-side facing the same direction, with the task space mostly in front of them. Kiyokawa et al. (2002), noticed that in collaborative MR, if the task space was between the users, communication was more natural, social and easier. A caveat to remember, as Prilla (2019) found, is that a lot of previous work on collaborative MR is based on older devices, whereas the technology is improving rapidly, and newer devices provide richer MR experiences and more immersion.

Most XR device research focuses on individual users in laboratory settings, often with generic tasks. In contrast, an airliner flight deck (real or simulated) offers a unique research environment due to its safety-critical, controlled, and complex nature, with real-world implications for pilots and flight operations. Flight crews, as experts, work in a familiar setting, following well-rehearsed procedures and standard communication, unlike undergraduate students performing, e.g., generic visual search tasks in labs with narrow task descriptions. A CSE approach requires a naturalistic environment, which sets this study apart from typical XR research. While XR device use in flight decks has been explored, it has generally focused on single-pilot operations. (e.g., Li et al., 2020; Li et al., 2022b, Oh et al., 2021). Besides XR devices, other instruments such as eye-tracking solutions have been used on flight decks for decades (Ziv, 2016) and more recent studies (e.g., Knabl-Schmitz et al., 2023) have started to show interest in crew interaction in multi-crew environments.

Research gap identified

During the literature review, the author could not find relevant research on multi-crew coordination in a flight deck environment, where specifically a modern head-mounted XR device incorporating passthrough video was used. This is most probably because viable devices have only just recently become commercially available, as noted in the introduction earlier. Single pilot operations differ greatly from a contemporary multi-crew operation, where established concepts such as multi-crew coordination, standard operating procedures and crew resource management (or EBT) guide and describe the work being done by the crew. Research that comes closest to the one suggested here, is the work done on flight crew coordination using night vision goggles (NVG) dating as far back as the 1980's (Kotulak, 1986). Though the research is relevant in other aspects, the NVG as a device differs quite a lot from contemporary mixed reality headsets with passthrough vision. Also as mentioned in the previous section, extended reality devices using passthrough vision have specific features and implications for usage that can fundamentally differ from optical see-through ones.

The primary scientific object of interest is defined here as crew coordination. Supplementing the primary object, workload (Casner & Gore, 2010) and the choreography of joint activity (Klein et al., 2005) are identified as secondary interests. With these in mind, the research question is formulated as follows:

"How does using passthrough video for vision influence flight crew coordination?"

Considering the above-mentioned aspects, the research question of this study is argued to be relevant and novel.

Research design

In this study a full flight simulator was used with professional airline crews. The research design is inspired by and draws from case study research (Yin, 2018). An important feature of case study research is that it is interested in retaining a real-world context (p. 15) and that it looks at the case as a whole, not just at the variables (p. 41). Often in case study research, the phenomenon of interest and the context are not easily separable. From a JCS perspective (Woods & Hollnagel, 2006), the importance of context is also evident in this study, where coordination (i.e., the scientific object of interest) inside the flight deck is embedded in the work being done and the artefacts being used (Hutchins, 1995b; Klein et al., 2005).

Another option would have been a more traditional experimental design (e.g., Creswell & Creswell, 2018). However, it was decided early on, that experimental design would not be used for the following reasons. In contrast to a case study research, experimental design often tries to separate the phenomenon from its context by controlling it in a laboratory environment (Yin, 2018, p.15). Preferred theoretical perspectives favoured the inclusion of work context, instead of strict control of different variables. The exploration of new technology with a small population made it more interesting to try to generalize theories, instead of extrapolating probabilities. Doing a case study is about analytic generalization, as opposed to statistical generalization (Yin, p. 20-21, p. 56), where the generalization is to theoretical propositions, not to populations. In the end, the sample size would have also been arguably too small for a proper experimental design, and the timeline as well as resource constraints probably would not have worked out either.

Context referred to and used in this research might contribute to some confusion. Both real-world flying operations and simulator missions happen in a remarkably controlled environment. This is evident in the detailed way the work is prescribed in various SOPs, guidelines, rules and regulations. The highly prescribed nature of work concerns the whole ecosystem, including aircraft crews as well as other aviation stakeholders, such as air traffic control, maintenance and ground handling. The FFS can bring additional control to the context with manipulation of the environment and technical aspects, as well as through scenario design. Elaborating further, while case study research wants a real-world context, this research can be seen as a peculiar case where the 'real world' is the simulated world. This is because, while the flight simulator training of airline pilots tries to mimic the line operations with actual aircraft, simulator flying is also an essential part of the pilots' career and work. Throughout their career, pilots spend hundreds or even thousands of hours inside the simulator, and performance there is evaluated and has a concrete effect on their career. While not necessarily safety critical, career-wise these simulator sessions can be high stakes situations for the pilots. So, for pilots then, the simulator environment can also be seen as one variation of 'real world' context, just like the line operations. Thus, the context and its control become a somewhat fuzzy notion in this study, where it is a blend of real-world elements and simulated control.

Instead of an experimental design, the research draws on the principles of an exploratory multiple case study (Yin, 2018). The attempt is to discover, what implications it might have to introduce this novel artefact (i.e., a head-mounted MR device with passthrough vision) to a multi-crew flight deck environment. To study the scientific object of interest, i.e., coordination, it's fidelity should be as high as possible. Naturally, this could best be observed in actual line flying operations. However, introducing XR headsets to that environment would be unsafe and not plausible from a legal standpoint. Also, it is reasonable to assume in the airline context, that these kinds of headsets will be mainly used in training environments, and that their arrival to an operational line flying environment is still far off in the future. Fidelity-wise, full flight simulators represent the next best thing. While the FFS is industry's best attempt at recreating the fidelity of actual line flying operations, it still lacks several aspects of the 'real thing', such as other actors (air traffic control, cabin crew, etc.) and authentic operational pressures. Regardless, it still provides a reasonably good representation of intra-crew coordination for the purposes of this study. A simulator is also a safe environment to test a headset, it is logistically doable and provides a controllable environment for scenario design.

Another confusion about the context that should be elaborated on, is that the probable use case of a video passthrough MR headset actually would not be inside an FFS, but probably in conjunction with some other lower fidelity device. But for our purposes of observing high-fidelity crew coordination, it was still thought best to bring the device in to the FFS environment.

Data collection

In short, each case consisted of an airline crew flying two simulator scenarios, where in one they were not using an XR headset and in the other similar scenario, they did use one. An exception is the last case, where the crew flew both scenarios without the headset, as a research control measure. The simulator session was observed and captured for later analysis, and after the session an interview was conducted where the crew could voice their experiences. There were 6 cases (i.e., crews) in total. In the following, the method is explained in more detail.

Data was collected first with a document analysis, where relevant parts of company manuals were studied. These included the aircraft manual (FCOM; Airbus, 2024) and approach charts (OM-C, see Appendix F). These acted as a reference to the 'work-as-imagined' (Hollnagel, 2009) and applied to all the

cases to be studied, because the crews came from the same company. Secondly, at the beginning of each case session, a short demographics questionnaire form was given to the participants (see appendix A). The form mapped out some basic background information. At this point, a classroom briefing was also conducted to prepare the crew for the upcoming simulator session. The briefing contained an outline of the upcoming session and some necessary instructions (see Appendix B). At the end of the briefing, participants were acquainted with the modified Bedford workload scale (Casner & Gore, 2010) and were also given the opportunity to try out the MR headset in the classroom environment.

The simulator session consisted of two parts, scenarios A and B. The whole session was recorded with cameras for video and audio, while also being observed in real time by the researcher, who occupied the instructor seat of the simulator and operated the necessary simulation controls (see Appendix C). Both scenarios were made of three phases, and after each phase the scenario was paused and both crew members filled out a Bedford workload scale questionnaire form with pen and paper, where they independently self-evaluated their workload during the previous phase of the scenario. This was done while seated in the simulator. The crew was also instructed not to discuss about filling the workload scale, in order not to affect the other crew member's input.

After the simulator session, the crew returned to a classroom where a semi-structured interview was conducted (Creswell & Creswell, 2018). The session was a face-to-face guided conversation (Yin, 2018, p. 118) between the researcher and both crew members, and it was recorded using a microphone. For the interview questions, see Appendix D. Capturing and recording of the headset's passthrough video and the simulator's flight data would have been possible, but was omitted due to workload and scope reasons. An important part of case study research is building a case study database (Yin, pp. 130-134). This was done on the author’s personal computer to better support the analysis phase of the research.

Research ethics

Conducting research involving human participants needs careful consideration of ethical principles. The participants were properly briefed in accordance with the Lund University ethical guidelines (https://www.researchethics.lu.se) about:

- the purpose of the research
- data collection methods to be used

- how the results are used and how confidentiality is ensured
- the consequences and risks that the research may entail
- the person responsible for the research
- that participation is voluntary and
- that the volunteer has the right to opt out of the research at any time

The data that was collected was anonymised and stored on a separate private hard drive. The participants had the right to request deletion of their data from the research project. After being briefed on the ethical aspects of the research, the participants signed a consent form indicating that they gave their informed consent (see Appendix E). At the end of the session, they received a debriefing where they were given a chance to ask further questions about the research.

Theoretical perspective

The described data collection method draws from a constructivist approach in case study research design, where it is "attempting to capture the perspectives of different participants and ... how their different meanings illuminate the topic of research." (Yin, 2018, p.16) The theoretical perspective can also be described as relativist (Yin, 2018, p. 16), because each crew and individual crew member experiences the session differently, and because there is no 'truth out there'. Instead, there are multiple realities and meanings, and the researcher is interested in how the crews make sense of how the headset is influencing their way of working. The findings are also observer dependent, i.e., what the crew think they are doing is not the same as what the researcher thinks they are doing. This research tried to establish triangulation through observation, query (the workload scale) and interview (Yin, 2018, p. 43). Data triangulation was done through different data sources, and theory triangulation was established with different perspectives on the same data. According to Yin (2018, pp. 127-128) multiple sources of evidence and converging lines of inquiry strengthens construct validity.

Quantitative performance metrics were deemed unsuitable for this research. It is true, that performance metrics (e.g., flight data from the simulator) are often fairly easy to obtain in non-intrusive ways, but as Hollnagel & Woods (2005, p.55) warn us, it is "an all-too-common experience ... that measurements are chosen because they are possible to make and because there is technology available, rather than because they are meaningful." Salmon et al. (2009) review and highlight problems with

different methods of measuring situation awareness, performance measures among them. Although they write about the problems with performance measures related to situation awareness, arguably the same applies for crew coordination as well, because both are essentially constructs. Paraphrasing the same arguments for crew coordination, one could say that exemplary performance during a task does not necessarily point to a crew having good coordination, and vice versa, where it may be that efficient performance is achieved despite inadequate levels of coordination, or that poor performance is achieved regardless of good coordination (Salmon et al., 2009, p.49). Besides not crashing the aircraft, defining what is 'good' performance only from raw flight data is not without problems either.

Hence, the aim is not to evaluate the performance of the crews by normative standards, but instead to look inside the flight deck and describe how the work is done by the joint cognitive system. As Salmon et al. (2009) and Hollnagel & Woods (2005) point out, performance measures can still be valuable as supporting evidence used in combination with other sources. However, due to scope reasons, it was deemed not efficient to use performance metrics, such as simulator flight data, in this research.

Selection of informants and scenario design

The scenarios were constructed to provide the crews with diverse experiences, while keeping in mind the resources available. For the selection of cases and informants, it was chosen to use experienced crews from the researchers own company, Finnair. Being a Finnish flag carrier airline, it provided a relatively homogeneous pool of pilots that were easily available for the researcher. The homogeneity, at least superficially, included common language (Finnish) and similar training background. Using crews from a single company was also convenient because the manuals and procedures would be the same for all cases. Collaboration with Finnair Flight Academy enabled the use of the company owned Airbus A330 full flight simulator. The selection of informants this way ensured that each pilot would have multiple years of service in the company and thousands of hours of flying Airbus-family aircraft. They would also be type-rated to the A330 and familiar with the specific simulator unit and its environment.

Selecting which head-worn XR device should be used was also important. Logistics and practical scheduling issues proved somewhat decisive. Viable options included the Meta Quest 3, Apple Vision Pro and Varjo XR-4. Meta Quest 3 was more readily available than the Vision Pro, while also having a larger vertical field of view. Varjo XR-4 would have had superior technical performance, but the availability of it

and the requirement to have it connected to a new and powerful PC would have made the use of it in an FFS environment difficult and impractical, given the resources available. The Quest 3 was selected, because it was affordable, available, it had a good field of view, and it was easily portable as a standalone device. The major shortcoming of the Quest 3, compared to the others, was the smaller resolution of its displays. The Quest 3 was used with a more comfortable Elite Strap.

In all cases, the first scenario was flown without the headsets. During a pause between the scenarios, the headsets were donned, and the second scenario was flown with them. Virtual elements were omitted from the vision of the user and only passthrough video was used during the session. This was done to keep the research within given scope and to reduce the complexity of the setup.

Flying two scenarios, with and without the headset, had the benefit of giving the crew a baseline to reflect their experiences on. The scenarios were temporally close, being flown back-to-back. They were also contextually close, having a similar structure (see Appendix F). The two scenarios gave the researcher also a chance to compare observations. Having observed both scenarios, the researcher did not have to solely rely on the crew's own reflections. Also, the Bedford workload scale was more informative with two similar scenarios. Both scenarios had 3 phases, where each was designed to elicit different requirements for crew coordination. The phases included an approach briefing, some straightforward malfunction handling and a relatively challenging visual approach. The details of the scenarios and their construction can be found in appendix F.

Replication logic

As said earlier, this research draws from the principles of case study research, articulated by Yin (2018). The research design is inspired by Yin's exploratory multiple case study, where the cases represent holistic individual cases (p. 55). The replication logic for the 6 cases was designed as follows to provide external validity (Yin, 2018, p. 43):

- Cases 1-5 were literal replication
    - #1 was a pilot case study to test out equipment and protocol
    - #3-5 were added with the Bedford workload scale form, because tentative findings from the first two cases suggested that workload was interesting
    - The first five cases were predicted to have similar results

- Case 6 was a theoretical replication
    - The crew flew both scenarios without the headset
    - Predicting contrasting results, but for anticipated reasons (i.e., not wearing a headset)
    - Case 6 also represented a subgroup by itself, but it was not deemed necessary to have another case to provide literal replication. This was because the design of two similar scenarios arguably provides enough literal replication within the case itself.

The research does not aim for a sampling logic and does not claim to represent the whole 'universe'. As Yin (2018, p. 56) underlines, case studies are not for assessing the prevalence of phenomena. Drawing from the principles of an exploratory case study, there should thus also be criteria for judging it successful. The field of XR devices in pilot training is still nascent and this research occupies an area not well researched, i.e., XR devices in multi-crew flight decks. Thus, for this paper's exploration to be successful, identification of operational measures, and propositions to be examined in later studies would arguably be good success criteria (Yin, 2018, p.28).

Analytical framework

Yin (2018) describes several analytic strategies how to approach the data. In the first stage, beginning already during the formulation of the case study database, it is natural to just play with the data. This could mean creating visual displays, tabulating the frequency of events, arranging the datasets in various ways, creating matrices etc. (p. 167). The data can then be worked from ground up or top down relying on theoretical propositions (pp. 168-169). In practice, the strategy here was an iterative process of going through the data multiple times, alternating between relying on theoretical propositions and working the data from the ground up, in essence as a mixture of both. This was because the theoretical basis and most of the protocol questions derived from it were present from the start of the analytic process and could not be ignored. An important analytic strategy not to be neglected and which works in combination with the other two strategies, is the examination of plausible rival explanations (Yin, 2018, p. 172). Covering rival explanations is essential for the credibility of the analytic generalizations that the case study tries to make. As Yin (2018, p.41) points out, it is good to keep in mind that the generalizing is from the case study, not the individual cases.

Theoretical frameworks in the centre of the analysis and synthesis will be the coordination of joint activity (Klein et al., 2005) and joint cognitive systems (Hollnagel & Woods, 2005; Woods & Hollnagel, 2006). The (simulated) aircraft and its crew are seen as a joint cognitive system, where the aircraft systems and the artefacts used are included as important parts of the whole to be studied (Hollnagel & Woods, 2005). The choreography of joint activity (Klein et al., 2005) gives a structured way of analysing the crew coordination by looking at the phases, signalling, coordination devices and coordination costs of the activity.

Protocol questions

An exploratory case study should be preceded with statements or questions what is to be explored (Yin, 2018, p. 36). While the main research question here is "How does using passthrough video for vision influence flight crew coordination?" it must be explored with further detailed theoretical propositions and protocol questions. According to Yin (2018, p. 94), already in the data collection phase of the research, the protocol questions should be kept in mind. This means that collecting data and the potential sources of evidence should address the questions that support answering the actual research question. This was accomplished by recording the simulator session from different angles to capture the events for later analysis, while during the session the researcher observed the events in real-time and made notes. These notes were used in the interview part to elicit knowledge from the participants. Also, during the interview, the protocol questions played at least an implicit role in carrying on the discussion. This way, the questions were a part of the data collection phase of the study linking the aims of the study to the exploration.

Because the scientific object of interest is crew coordination, the protocol questions revolved around different aspects of what effects the MR headset could have on it. The questions were formulated as follows:

- Does not seeing your crewmates' face affect coordination?
- Does not seeing your periphery affect coordination?
- Does passthrough vision affect workload?
- Does passthrough vision incur coordination costs?
- Does passthrough vision affect signalling and phases?

The first two questions were informed by the existing literature (e.g., Bailenson et al., 2024) and the theoretical proposition that wearing a relatively bulky headset, that obscures your own vision and also the other crew member's ability to see your face fully, probably affects how the crew coordinates their work, e.g., by having to turn their heads more often to see the other person or displays not in their central part of vision. The third question arose after the first two cases reported increased workloads in their normal work routines. Following this, a Bedford workload scale questionnaire was used with the remainder of the cases to probe specifically about the perceived workload of the crew members. The last two questions are derived from Klein et al. (2005), where the coordination of joint activity is described in detail. The theoretical proposition here was, that the MR headset would slow down the routine actions that crew members take (e.g., by having to turn their heads more), and this would incur delays or increased workload, i.e., coordination costs. While these coordination costs would have an effect on signalling and phases, it could also be possible that the headset would have effects in other ways as well, e.g., with increased finger pointing due to lack of gaze information or by having the other crew member miss an important signal that the other was making.

During the initial video review, it became apparent that keeping a tally on eye-contact between the pilots could become an interesting data source. The camera situated on the glareshield gave a good view of the pilots facing it, enabling an accurate tally on eye-contact made, when the crews did not have the headset on. In scenario B, where the headsets were donned, it was not as straightforward. The headset prevented direct observation of the eyes and gaze of the pilots. However, the pilots were sitting and facing in the same direction, which meant that when they looked at each other they had to turn their heads quite a lot more, than if they were just observing the instruments and displays in front of them. This was exacerbated by the reduced FOV of the headset, which also made the head movement usually relatively sharp when looking at the other pilot. In effect, the researcher observing the video feed could thus be confident in their tally on eye-contact, even with the headsets on. Although it should be noted that this entails the assumption that when a pilot looked towards the face of the other pilot, they were seeking eye-contact.

The protocol questions above also inform the analysis phase of the research, and the analytical techniques used. The analytical techniques used are a way of linking data to propositions (Yin, 2018, p.

33). Yin describes several analytic techniques, of which three are applied in this study: pattern matching, explanation building and cross-case synthesis.

Pattern matching

For pattern matching, according to Yin (2018, p. 175), it is essential to have predicted patterns before collecting the data and we already touched on some of them above. The first predicted pattern was that the phases and signalling will be slower because of using the headset and this would incur coordination costs and increase workload. The second predicted pattern was that the pilots need to turn their heads more often when speaking with each other, due to the reduced field of view. The third predicted pattern was articulated after the first two cases, before the third case and when the Bedford workload scale was introduced. The prediction was that each phase of the simulator session would be subjectively rated with an increased workload when using the headset, compared to the phase where it was not used. This lacks precision due to too few data points for statistical analysis, however a gross pattern match can still be sufficient (Yin, 2018, p. 178). With pattern matching, the first five cases attempted literal replication logic, so an individual anomaly in one could be ruled out with the other four.

Explanation building

A Yin (2018, p. 180) explains, the process of explanation building is iterative, where a tentative explanatory proposition is compared with data from the case study, revised accordingly, and then compared again. In multiple case study research like this one, the comparison is made with the other cases as well. These iterations refine the explanation and can be seen being partly based on the theoretical propositions from the outset and partly on the data from the case study. Here, too, the plausible rival explanations must be addressed credibly and based on data, preferably from multiple cases. However, it should be kept in mind that in an exploratory case study research, the goal of explanation building is "not to conclude a study, but to develop ideas for further study" (Yin, 2018, p. 179). Thus, both techniques of pattern matching and explanation building employ the strategy of relying on theoretical propositions, but in the spirit of exploration, the iterative process also supports working the data from ground up, where novel things are discovered.

Cross-case synthesis

Having multiple cases lends itself naturally to doing cross-case synthesis. Yin (2018, p. 196) warns against using a reductionist approach typical to quantitative studies, where a cross-case synthesis is accomplished by decomposing the cases to variables and then aggregating the data. As is commonly the situation, the small number of cases would not enable statistical analysis anyway. Instead of a variable-based approach, Yin (p. 196) recommends a case-based approach, where "the goal is to retain the integrity of the entire case and then to compare or synthesize any within-case patterns across the cases". This comes with the caveat that the research will rely strongly on argumentative interpretation, not numeric tallies (p. 198).

In this research there are 6 cases with 2 scenarios and 3 phases in each scenario. Within-case patterns can be searched from the case as a whole, or from each phase and scenario separately. These can then be compared to the other cases, e.g., synthesizing the third phases from scenario B together across all cases (i.e., visual approaches with the headset on). The earlier mentioned iterative process tries to establish tentative results by playing with data, case by case. This is followed by cross-case analysis and attempts to answer study questions and produce rival hypotheses. At some point the iterations reach saturation, conclusions can be made, and the success criteria of the case study research are evaluated.

Findings

Limitations

One of the main limitations for this study came from using a more low-end consumer device, i.e., the Meta Quest 3. The crews reported the low display resolution of the device as one of the features that created the biggest difficulties for them during the scenario B. There are high-end devices that have displays with better resolutions (e.g., Varjo XR-4), so a study conducted with one of those could have easily fixed issues that arise explicitly from display resolution.

It was also discovered that the simulator visual (projector-type) induced, probably due to the refresh rate, a flickering effect when viewed through the Quest 3 headset. This was not present during a test session conducted beforehand to establish the feasibility of using the Quest 3. Later it was discovered that Meta had released an update after the test session for the Quest 3 that had changed the refresh rate of the Q3 display and removed the option to toggle between different refresh rates. The new refresh rate thus probably was resonating with the simulator visual refresh rate, causing it to flicker uncomfortably for the headset wearer. The crews used the sun visors to mitigate the effects of the flickering screen, when there was no need to look outside the aircraft (i.e., during phases 1 and 2). Luckily, in the research design phase, the choice was made to leave out quantitative performance measurements, because the flickering visual would have probably been disastrous for the study, if performance metrics were the main interest.

From a comfort aspect, probably mostly due to the flickering simulator visual, unsurprisingly the crews reported that "flying with this headset was not pleasant" (Captain, crew 3), or that "the ergonomics of the headset with a longer session would not be good ... if the session would have been any longer, you would start to feel the weight of the headset on your head" (Copilot, crew 4). A most descriptive quote came from the copilot of crew 5: "In the end [of the scenario] you felt that you wanted to take the headset off."

For this study, it is relevant to be able to try to separate the 'noise' effect that the low resolution and unpleasant flickering visual had and find the other interesting aspects that wearing a MR headset had on crew coordination. These would include having a reduced FOV, dealing with flying while having an apparatus mounted on your head, and other distortions of a passthrough display. Luckily the research

method with its multiple sources of evidence and converging lines of inquiry enabled some good findings and arguments to be made that apply to situations that are not handicapped the same way this study was.

Overview of the phases

The scenarios and their three phases were designed to elicit diverse situations and experiences for the crews and give opportunities for observable behaviours for the researcher to see. In the approach briefing of phase 1, the crews were given an opportunity to set their own pace of doing things, with the autopilot flying a holding pattern with more than enough fuel and time. The SOP gives instructions and a briefing template that crews can use to structure their approach preparations and the briefing itself. The briefing is usually conducted in a conversational manner, and it varies from crew to crew. The SOP acts as a coordination device, however, it leaves the crew with considerable leeway in how to go about it. The reported effects of the headset were thus quite varied between crews, reflecting the variation in personal styles and variation in conducting the approach preparation and briefing.

Phase 2 had an abnormal procedure creating a higher tempo with some time pressure, but the aircraft was still allowed to fly a holding pattern on autopilot, giving the crews an opportunity to solely have their focus inside the flight deck. An abnormal procedure (engine failure and engine fire in scenarios A and B, respectively) is straightforward and sequential in nature, having a focus on instruments, displays and pressing buttons. The procedure includes both memorized actions and computer dictated actions (ECAM actions), and as a coordination device it guides the flow of the procedure very strongly and is a major contributor to the coordination of the JCS. It was easy to observe the tempo change that occurred with the master alarm coming on, indicating the onset of engine failure (or fire). Many of the pilots' posture changed, communication became more standardized, and they switched focus to the abnormal procedure. The interaction was mostly driven by the procedure and there was less room for applying custom behaviours. In phase 2, effects of the headset were reported more minimal and were similar between crews. One captain (crew 3) even noted that because he was so focused he forgot that he had the headset on at one point during phase 2.

As will be later explored through the concept of workload, the crews 1...5 felt that the phase 3 with its high tempo and event-driven visual approach was the most demanding. Unlike phases 1 and 2, phase 3 had the captain fly the aircraft manually, which changes the nature and demands of the task

sharing and roles, i.e., pilot flying and pilot monitoring. The crews were also no longer able to set their own pace for actions, because of the event-driven nature of a forward moving aircraft on the approach. Arguably being the most demanding phase from a coordination perspective, phase 3 thus brought out the most salient effects of using the headset, not least because of the difficulties created by the flickering simulator visual. As depicted in the method, crew 6 differed in that they flew both scenarios without a headset. As expected, the results were different compared to the other 5 crews. Crew 6 flew both phase 3 visual approaches in a similar fashion with nonchalant, almost minimal communication. For the observer, the coordination appeared as effortless and effective. Crew 6 also reported the phase 2 as being more demanding than the visual approach in phase 3. From an airport perspective, Split appeared to be the tougher one for the crews, with 3 go-arounds conducted (3 crews, 2 *without* the headset, 1 with the headset), while no go-arounds were done at Dubrovnik. The shorter final leg in Split might be one the reasons, making it a more demanding approach path. The airport-specific learning effect was mitigated by switching up the order of airports flown between cases.

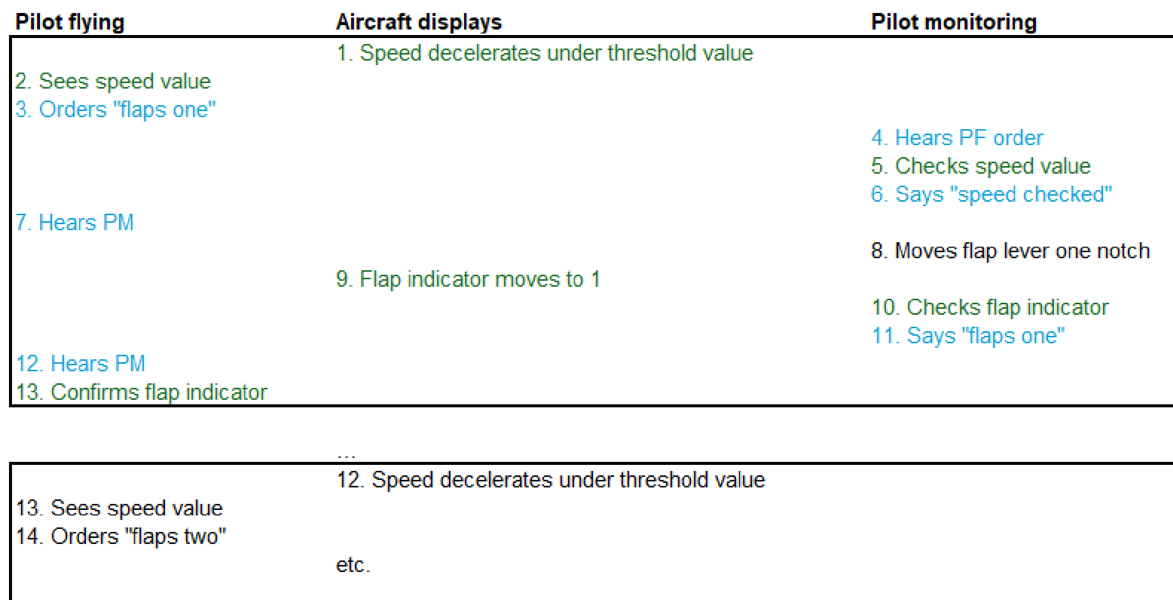
Examples of coordination

Before delving into the details of the findings, it is probably beneficial to give the reader a couple examples of coordination from the flight deck. Firstly, a generic 'by-the-book' example of a joint action from the Airbus flight crew operating manual, then one example of a minor breakdown in joint action from crew 2. For brevity, these examples will be simplified somewhat.

In Figure 3, a generic example is given, where changing the aircraft configuration is depicted as a phase and the associated signalling is described, following Klein et al. (2005). Signals are exchanged between the pilots and the aircraft systems, and the SOP acts as a coordination device that guides the sequential nature of the choreography. Noticeable is, that while only one actual action (lever movement) takes place, the phase in its prescribed form has 13 steps. This is common for many things done by the flight crew, depicting the safety critical nature of work on a flight deck, while also highlighting the costs of coordination.

Figure 3

Coordination example: configuration change



Signaling aircraft <-> pilot
Signaling pilot <-> pilot
Closed loop voice communication (subphases within phases)

3…13 = A phase consisting of changing the aircraft configuration from no flaps to flaps one
Usually during this phase, not much else is done to allow the steps and signals of the phase to be completed uninterrupted.
Notice there is only one actual action in this phase: PM moving the flap lever.
So for one action, there can be found at least 13 steps in this phase.

Similar to the example in Figure 3, usually it is desirable for the crew to complete many of the different phases in discrete fashion, especially when they involve manipulating the critical controls of the aircraft. The aircraft manuals and procedures also support this. Both pilots focusing on one phase at a time before starting the next one mitigates the risk of forgetting or missing something crucial. However, the real-world complexities often do not allow for this, forcing the crew to have to be able to also manage several phases concurrently, if necessary. Figures 4 and 5 depict an example of a minor breakdown in joint activity due to several phases getting jumbled up by crew 2 in their visual approach. It also shows how the crew is able to rather easily recover from this. Figure 4 shows a neat 'textbook' version of how the phases are imagined happening in a discrete and sequential fashion by the SOP (Airbus FCOM, 2024). Figure 5 is an abbreviated description of an event, taken from observational data (Crew 2, Scenario A, Phase 3, i.e., visual approach without headsets). Observation from the camera footage suggests that the situation is brought about by most likely the pilot flying (PF) realizing that they have a bit too much energy for the

approach and so there is a need to quickly create more drag by changing the aircraft configuration faster than the prescribed procedure would allow. The PF does this by opening new phases before the earlier ones have been 'properly' closed by the pilot monitoring (PM). This can also be seen as a signal of urgency for the other pilot and is not an uncommon occurrence on a flight deck. It is probably the PF judging the coordination costs of the prescribed procedure to be too large for this particular high workload snapshot of time, demanding adaptation. The PM's reluctance to close out the first phase without confirmation for the missing 'flight directors off' command could be seen as an example of an attempt to maintain and repair the common ground between the crew members. Apparently, he does not want to assume that the PF just forgot it, he wants to be sure. In doing so, unfortunately, there is a disruption of common ground elsewhere: the intended position of the flaps. Judging from the camera footage and crew's deviation from the prescribed procedure, there is a short time span, where the pilots have a differing understanding of the configuration status of the aircraft.

Figure 4

Coordination example: prescribed transition to manual flight

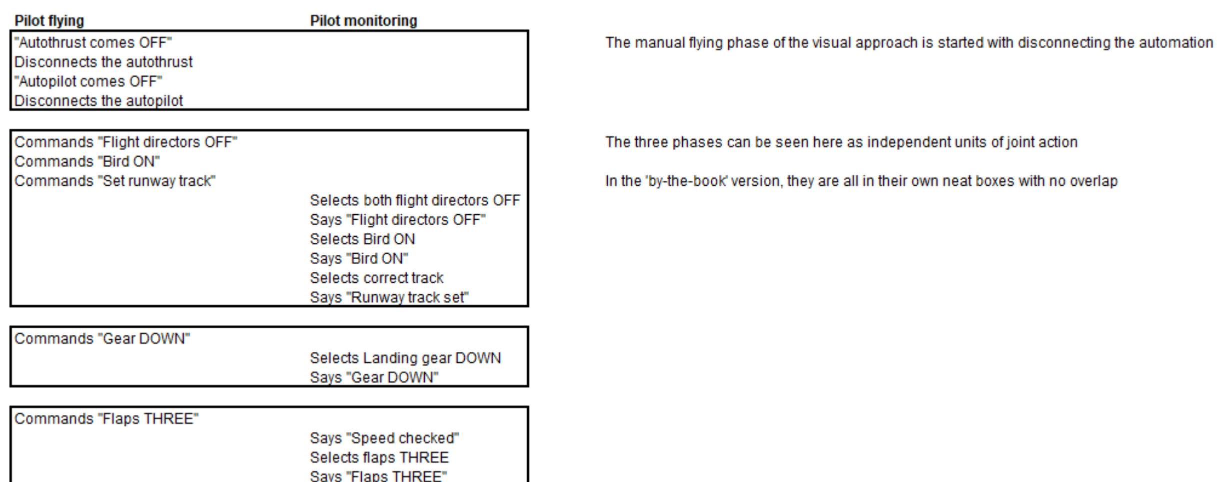
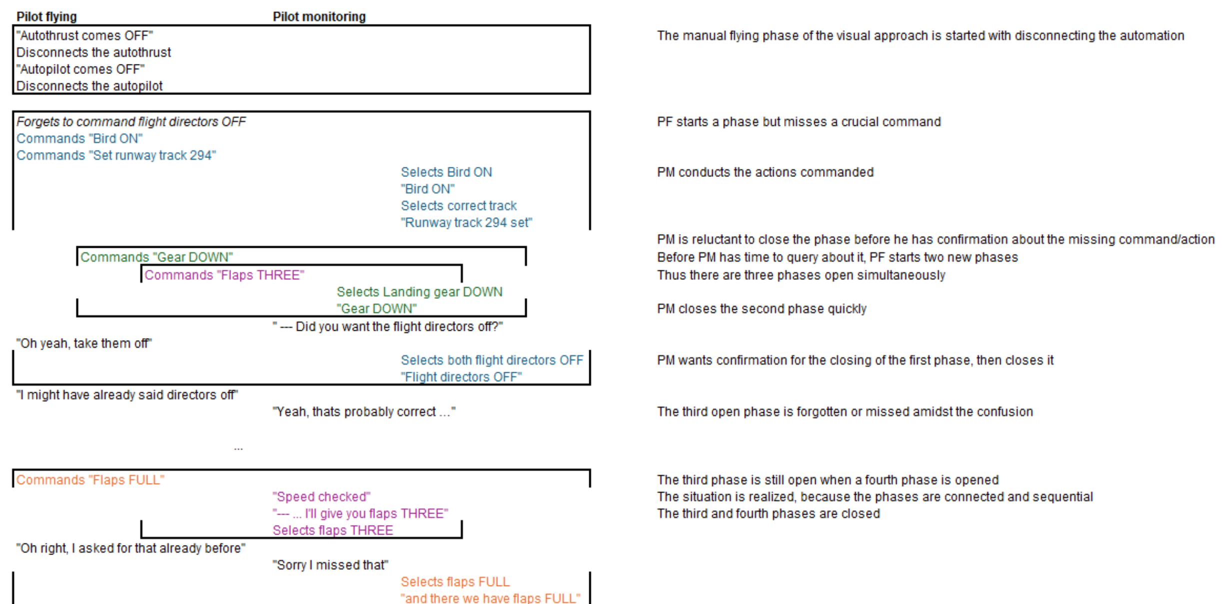


Figure 5

Coordination example: observed transition to manual flight



It is crucial to highlight, that the crew was seemingly able to handle both occurrences (i.e., the high energy situation and breakdown in joint activity) and land the aircraft successfully. This event is an example of normal everyday work that for a casual observer probably looks effortless and nonchalant, but when broken down and looked at from a 'choreography of joint action' perspective, it reveals the interesting ways of how pilots, or rather the JCS, copes with the complexities of real-world work-as-done. In the following, we dig deeper into these nuances of crew coordination and what effects the headset had on them.

Observing and tabulating head turning and eye-contact

Going through the observational data it was noticed that crew members establishing eye-contact and turning their heads to see each other was important, but not straightforward. The frequencies and styles varied from crew to crew and between individual pilots. There were clearly those who did it more, and those who did it less. It was thought interesting to try to count the times the crews made eye-contact or looked at each other and see if there were any notable differences between phases and scenarios. The precision of tabulating eye-contacts and head turning was imperfect for several reasons. Firstly, in scenario B the eyes of the pilots were obscured by the headset, so the "eye-contact" had to be inferred from how the pilots turned their heads. Arguably this could still be done with reasonable accuracy, because the pilots

were facing the same direction, it made it necessary for them to turn their heads quite a bit to make 'eye-contact', usually accompanied by a rather sharp head turning motion that made it clearly notable. Secondly, the style of making eye-contact made counting more difficult at some instances, e.g., when the crew maintained eye-contact for prolonged periods of time or when the other pilot spoke while looking away and the other kept looking at them continuously. Regardless, some gross pattern matching could still arguably be established from the tabulated data that complements the interviews. In figures 6 and 7, the frequencies can be seen in which the pilots initiated eye-contact (or turned their head toward the other pilot) and if the other pilot reciprocated (i.e., looked back and established eye-contact). The frequencies were counted visually from the camera footage facing the pilots (GoPro on the glareshield).

Figure 6

Eye-contact observations, phase 1

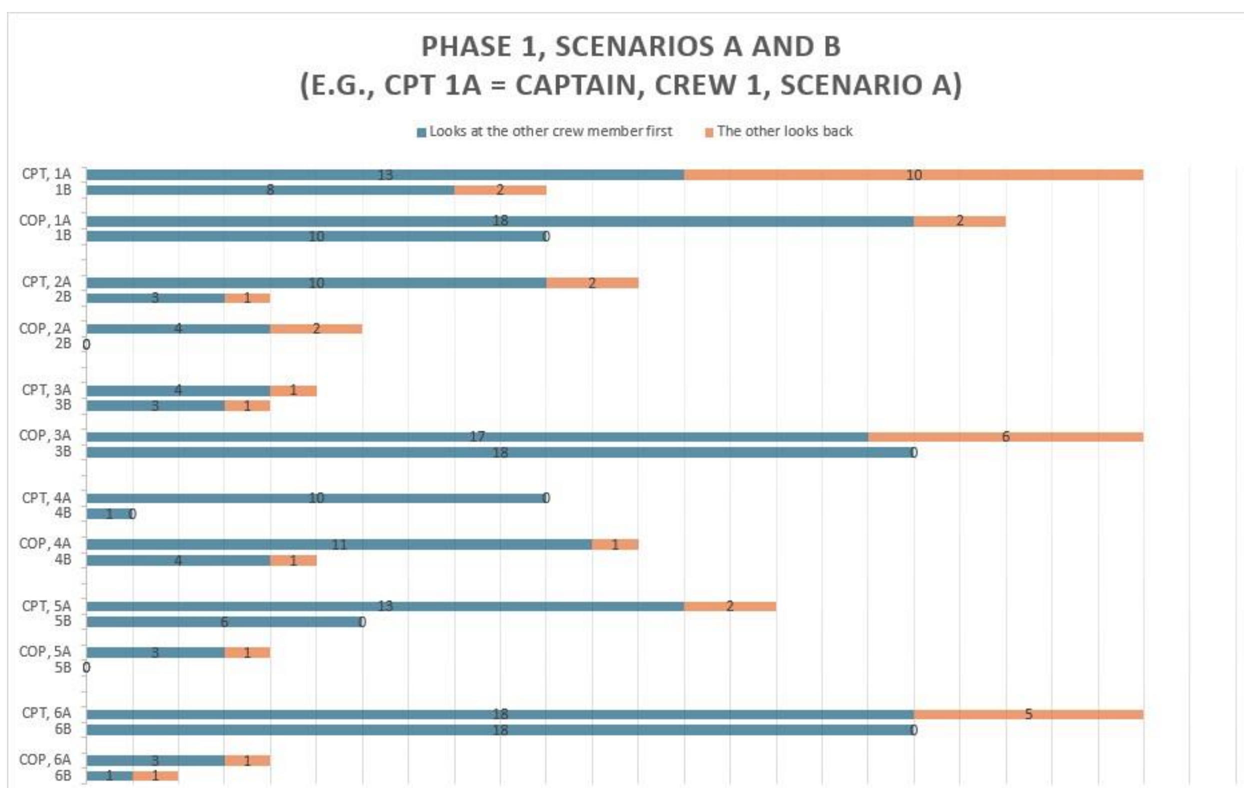
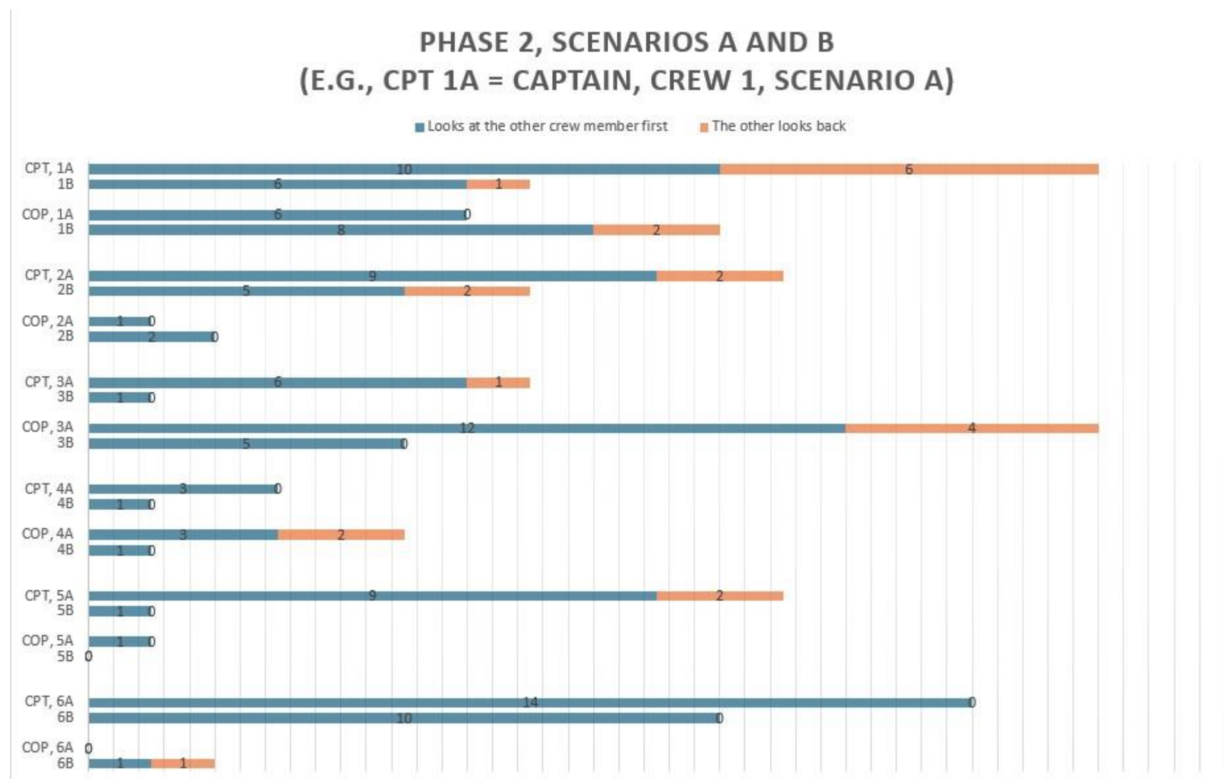


Figure 7

Eye-contact observations, phase 2



Exploring the non-verbal communication is beyond the scope of this study, but some nuances of 'looking at each other' found during the sessions might be beneficial to point out. When one initiates the head turn, in what way does the other reciprocate? Others do it by looking back, some might acknowledge it with a thumbs up. Is it always the same pilot that does the initiating? Or is it connected to a role or a turn in speaking? One might turn their head only halfway and not look at the other explicitly, using only their peripheral vision. There were crews that seemingly enjoyed establishing plentiful eye-contact, whereas others appeared to not really be interested in it almost at all. Also, the direction of speaking (i.e., orientation of your face and mouth) seems to act as a means to direct the attention of the other person, e.g., towards the displays or their iPad etc. Likewise, for establishing eye-contact, speaking towards the other person acts as a strong invitation to reciprocate eye-contact.

Arguably, the numerical tallies gathered are inconclusive by themselves but suggest some plausible arguments. Counting both pilots, in only 1 phase out of 20 were there *more* reciprocation in head turning with the headset than without it. 12 instances had less and 7 had the equal amount. This would suggest

that the headset might hamper the ability to reciprocate eye-contact, when the other pilot initiates it. This is a reasonable assumption knowing that the headset reduces the pilot's FOV, making it more difficult to see if the other pilot is looking at you. For most pilots (Phase 1: 9 out of 10, Phase 2: 8 out of 10), there seemed to be clear differences in the number of times they tried to look at the other pilot between the scenarios. 17 out of 20 phases had the pilot turn their head less towards the other pilot, when donning the headset. Another suggestion from the observational data alone would thus be, that the headset might make some pilots more passive regarding turning their head towards the other pilot. However, no other clear overall patterns relating to eye-contact and head turning seem to emerge across the crews or cases in phases 1 and 2, and the sample size is also too small to make any meaningful statistical analysis, as was noted in the research design section. Phase 3, i.e., the visual approach, did produce an interesting finding: no pilot in neither scenario looked at the other pilot even once during the visual approach, after the autopilot was switched off. This would suggest that the style of crew coordination is context, and so in this study, phase dependent.

The video footage of the crews flying the scenarios was reviewed, and besides counting the number of eye-contacts, there was also an effort to determine what were the situations when eye-contact was sought out and seemed important to the observer. With no other method than just observing and using the author's personal experience of working as a pilot, the findings should be considered as tentative, in line with the exploratory stance of the study. Based on the observations, it appeared that eye-contact was mostly sought out in situations, where a phase or a sub-phase of joint action was completed, and the crew wanted to confirm their mutual understanding of the situation or come to a decision regarding a plan of action. The SOP and the briefing template do not give detailed support for flying a non-standard visual approach, such as the ones flown in the study scenarios. All crews spent a fair amount of time thus going through the details of how the approach would be flown (i.e., flight path, speed, configuration, FMS inputs). It was in these kinds of 'non-standard' moments that eye-contact was usually present.

Does not seeing your periphery or the face of your crew member affect coordination?

Counting head turning and eye-contact from videos only brings you so far, so it was all the more important to hear what the crews themselves said about not having peripheral vision of the other crew

member, or not seeing their face properly. There were those that felt that the headset did not affect their ability to know what the other pilot was doing: "We followed the SOP so ... I didn't find myself wondering what the other pilot is doing next to me" (Captain, Crew 4); and those that did not miss their peripheral vision: "Regarding the reduced field of view, it did not bother me" (Captain, Crew 3). All crews reported during the interviews, one way or another, that following the SOP was a key component in knowing what the other pilot is doing or for anticipating what is to be done next. Crucially, Crew 3 raised the notion that if the other pilot is NOT doing things according to SOP, you could not keep up with them, because of the reduced FOV.

Regarding the reports of how it felt when the headset obscured the facial cues and features of the other crew member, there was no straightforward answer either. Some found it funny that the other person was "wearing a mask" (Captain, crew 3) or weird in that they looked like an "imaginary pilot" with the headset on (Copilot, crew 2). Copilot of crew 3 felt that seeing the other person's face was not important "because [today] it was not about emotions ... if you wanted to know if the other person was angry or happy, then yes, but not today in this environment." It might've had an influence, that the crew 3 knew each other beforehand and the session was observed to be light-hearted and conducted in an overall good mood.

Others found communication more troublesome with the headset. The captain of crew 1 said: "Crew communication includes looking at the other pilot ... if they look back into your eyes, you somehow have a better feeling, that the thing you just said was registered and understood ... all this kind of non-verbal part of communication is left out [with the headset] ... even though the guy is sitting next to you ... but the non-verbal part ... eye-contact, nodding, understanding facial expressions, and the like ... the communication is different without it [when using the headset]." Crew 3 agreed to the effect that the headset would slow down the more subtle and nuanced communication, and crew 5 noted that if you know the other person well, the effect of the headset might not be as big, but there would nevertheless be a performance drop. The copilot of crew 5 also thought that the lack of eye-contact and peripheral vision is "detrimental" to communication.

Regarding the reduced FOV and obscured facial features, there were interesting reports of feelings of loneliness. The captain of crew 2: "[the headset] reduced my field of vision considerably, I

could not see what the other person was doing in my periphery ... it was almost like I was alone there in a way … I just heard some voice there and I had to turn towards them to see." And even more with the copilot of crew 5: "[with the headset] you were not seeing the other person's eyes or face and the non-verbal part of it ... it felt that you were talking on the phone and not seeing them ... it felt that you were a lot more alone there and missing a connection, when doing the work."

Besides not seeing your crewmate in your periphery, the reduced FOV would also impact the amount of other surroundings you are seeing. These would include, e.g., various aircraft instruments, displays, the overhead panel and, crucially for the visual approach phase, the view outside. In addition to seeing lesser amounts in the periphery, the things you would see were also affected quite notably. Crew 1 reported that the vision through the passthrough video was "blurry", had "vibration and shaking", and at times it created a "disorienting effect, an illusion of movement". Other crews had similar experiences and unsurprisingly, the visual approach part was experienced as difficult: "seeing the runway was really hard" (crew 4); "it was really hard to look at the simulator visual with the headset on" (crew 5); "during a visual approach you are trying to imagine your trajectory, but it was difficult [when using the headset]" (crew 3) and "in short final the visual was restless and fluttering" and created "momentary large jerks" (crew 1). Knowing their way around the flight deck did not seem to be affected, and as the copilot of crew 4 pointed out, "because of muscle memory you could still find all the buttons, even if you could not see them clearly." All the informants were experienced pilots who had logged thousands of hours in an Airbus flight deck, so this was an unsurprising finding, and arguably all of them could probably operate most of the buttons and knobs even with their eyes closed. However, even if they knew their way around the flight deck, there were plenty of reports of different actions being slower than normal, because of the headset. This is particularly interesting, when thinking of the signalling, phases and costs of coordination.

Does passthrough vision affect signalling and phases?

A key interest of this study was to explore how passthrough vision affects signalling and phases. As predicted, during the interviews all crews reported that the resolution affected their ability to read the text on the aircraft displays and instruments. Slower reading would naturally have also slowed down the signalling and phases of the joint activity. Another interesting finding besides the resolution was articulated by the copilot, crew 3: "There is a blur when turning your head, but if you keep it still, it

focuses on the thing you're trying to look at." This same effect was noticed by the copilot of crew 5, and he also elaborated on what effects it had: "When switching the target you were looking at, there is a small 'autofocus' ... where it [the headset] focuses on the target ... you could notice it in your cross-scanning, it slows it down a lot ... and it might be that out of habit you are already scanning the next target, even though you did not have time to see and register the previous target ... because you are used to a certain kind of rhythm in your cross-scanning..." Copilot of crew 3 also had noticed this and described how it affected his communication: "Your workload increases ... for example in the visual approach, you had to focus much more on those things that normally you would just glance at ... it slows down all your more subtle communication, what you might want to say, like calling out vertical speeds ... you want to help as the pilot monitoring ... I tried to do it, but it was a lot harder." Captain of crew 2 also felt that his normal scanning techniques were affected: "If you tried to scan those basic things you normally would, at least with this particular device, you could not do it as efficiently as [you liked] ... you would rather have your head be still, so that the figure 'stayed as one'." Copilot of crew 3 also felt that in general, the gathering of information on the flight deck was harder: "when you normally just sit there, you would register quite a lot more information ... compared to when you are wearing the headset." All these reports strongly suggest that the fine-grained basic rhythm (including signalling and phases) of normal work was disrupted by the headset. "We followed SOP, even though it was slower", said the captain of crew 4.

With these reports in mind, one would expect different effects in different phases. In the first two phases the pilots would have their focus inside the flight deck, with less time pressure. In the visual approach phase, the pilots would instead have to turn their heads quite often and probably in a quicker fashion, when altering their gaze between the outside view and inside the flight deck. This would most likely exacerbate all the effects that were described above. The report from the copilot of crew 5 would seem to confirm this: "I am unable to monitor the primary displays, if I need to turn [my head] ... or there is more time consumed by the cross-scanning [of instruments], it is not as efficient." He also noted that "it mostly distracted my situation awareness ... and regarding workload management, the fact that you have to look at everything for a longer time ... when you're not used to it, it eats up your spare capacity." An interesting observation was made from the video data of crew 4 in scenario B, phase 3: when the captain switched off the autopilot and started manual flight and almost immediately when initiating a turn, he

commented that "oh jeez, this aircraft banks a lot!" This event was unfortunately missed at the time and not elaborated on in the interview but suggests that there might be some effects to the hand-eye coordination as well, at least when flying manually. This was corroborated by captain of crew 2: "Normally when flying a visual [approach], to look at the runway, you just need to turn your gaze. Now you had to turn your whole head ... the [headset display] visual confused your own head movement so that your hand coordination did not work [as normal] ... if you turned your head and looked elsewhere, if felt that your hand did some kind of a corrective manoeuvre [induced by the headset visual], but it was a wrong one." There were lots of effects then for the pilots to try to cope with. All the crews still managed to stay in control and successfully fly the scenarios, so what compensatory behaviours and adaptations did the crews have then?

Compensation and adaptation

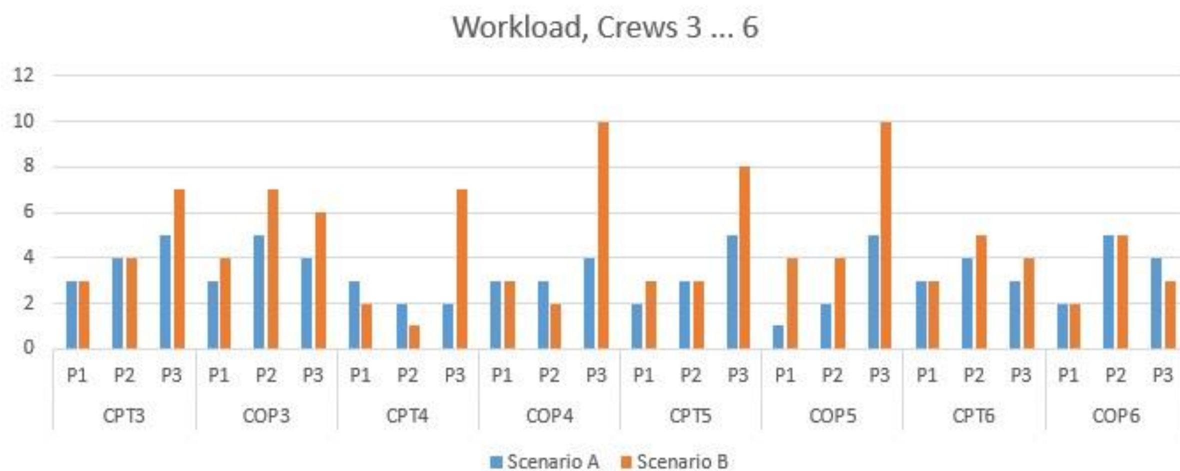
It would appear from some of the interviews, that the crews needed to increase effort and focus on the coordination to get through the flight. Crew 3 noted that with the headset the communication was better, because "it had to be". Regarding the closed loop nature of communication and signalling on the flight deck, the captain of crew 3 felt that the confirmation of the inputs became more pronounced: "the confirmation, that you actually read [your input] ... because of the resolution ... it is pronounced and a bit more clunky ... but you get it done more explicitly ... and you want the other pilot to confirm it ... so you're being more careful." Copilot, crew 2, had the same sort of experience: "Communication, situation awareness, and maybe even leadership and teamwork ... they were more pronounced, because both of us were 'flying blind'". Interestingly, crew 2 felt that even though there was more talk, it was less efficient. On the other hand, both crews 3 and 4 felt that they were not able to produce communication as fast as they would have liked. This is reminiscent of the efficiency-thoroughness trade-off (ETTO) principle of Hollnagel (2009). Looking at it through the perspective of ETTO: when you have more time, you can take things slower and be more thorough, but when pressed for time, you need to be more efficient. Also, if the workload is not as high (as in maybe the first two phases), you have more capacity to increase your effort, whereas in a tighter spot (as in phase 3) you might not have the same excess capacity, and the joint activity could start breaking down.

Workload and coordination costs

As was argued in the coordination examples earlier, a prescribed style of working through the phases of a configuration change has a rather high synchronization and communication overhead, i.e., time wasted in waiting for one entity to complete its work before the next one can begin, and the effort needed to manage the hand-off between the phases and sub-phases (Klein et al., 2005, p. 156). But as the examples also demonstrated, usually these coordination costs are there for a reason: to build and maintain common ground. Reports of actions being slower means a slower rhythm for signalling and phases, which would increase the overhead on synchronization and communication. Reports of not seeing the other crew member in a normal fashion, needing more communication, more cross-checking and verification, doing it more explicitly: this all feeds into the overhead of coordination costs. Different phases saw different manifestations of it. The first two phases had the crews flying on autopilot, focusing on things happening inside the flight deck, with less time pressure. Here it was possible to take things slower, be more explicit, more thorough and take advantage of the spare capacity that the situation allowed for them. Coordination costs are closely related to workload aspects. Ramping up the tempo in phase 3, with the higher coordination costs, should surely be evident in the workload that the crews experienced. This is indeed suggested by the Bedford scale data in Figure 8, for most pilots the workload seemed to be more manageable in both scenarios for the first two phases, compared to the third one. As with the eye-contact tallies, the subjective Bedford workload scale data is mainly circumstantial, and does not support very detailed conclusions. Especially because the scale was introduced from crew 3 onwards. 5 out of 6 pilots rated the phase 3 of scenario B (visual approach with the headset) as having the most workload. 11 out of 18 phases (CPT or COP) were reported as having more workload when wearing the headset, 4 being rated the same, and 3 as having less workload. As mentioned earlier, crew 6 flew both scenarios without the headset and during the interview said that the phase 2 had more workload than the phase 3 visual approach. This is reflected by their workload scale data as well and is in line with the argumentation above.

Figure 8

Bedford workload scale questionnaire data



During the interviews, unsurprisingly all crews reported that the flying was not easier with the headset and that the headset induced more workload for them overall. Clearly the biggest reported thing was, unfortunately from the perspective of the study, the flickering simulator visual when wearing the headset. The low resolution was another frequently reported difficulty. Although, even with some probing questions, it was not always easy to distinguish if the reported effects were in fact because of the resolution or other similar distorting effects of the headset display. Many crews reported capacity reductions, a concept related to the experience of workload (Wickens & Tsang, 2015). Captain of crew 5 said: "You had an extra layer there, produced by the headset ... an extra element, even though in principle it showed you everything there [the view forward] ... but it added a burden, from a performance perspective, you felt that you were drunk ... it made it considerably harder, not even taking account of the flickering effect [of the simulator visual]." Later in the interview he also added: "It even affects the procedures ... this extra thing, you have [the headset] ... it eats up your capacity ... so I think that even the procedures might go wrong [with it]." Crew 3 felt that "things take more time to accomplish", "you don't have spare time in between things", and because you have the timeline going forward this all "fills the workload 'bucket'." Copilot of crew 2 felt his capacity reduced, because "it is harder to listen, when you're not seeing clearly", while copilot of crew 5 described the difficulties that his slower actions created during the visual approach: "It was just so slow, that I didn't have the time ... I just couldn't find the exact

distance ... the altitude ... where we were supposed to be at ... it made it a lot harder, it made me freeze..." When talking about the core competencies, on a general level all the crews felt that their situation awareness was worse with the headset on. This was reflected in a comment from captain of crew 1, describing that in general, he felt more "insecure" throughout the flight.

Despite the challenges, the crews were able to adapt and stay in control. An example, that features many aspects of the findings described previously, comes from the visual approach of crew 2 in scenario B (headsets on). The captain of crew 2 was the only one in the study to opt for using manual thrust during the approaches. This means that he would need to handle the thrust levers himself, and thus it requires him scanning the engine parameters frequently, in addition to the normal instrument scan. Probably because of the blurring effect created by the head movements, the captain (just as he told in the interview) seemed to prefer to keep his head fairly still and focus on looking outside. This made it so, that his scanning of the instruments was more infrequent, which in turn made the copilot read out the key parameters out loud more frequently for him. It should be noted that this compensatory action was made without any request or prior agreement, making it one of those subtle but important features of effective teamwork. The copilot was reading the situation and acting accordingly. Later this working agreement became more overt, when the captain explicitly requested that the copilot would also read out loud the engine parameters that he currently had selected with just his hand-feel. The copilot obliged, and assumably took this as a signal that his call outs were indeed beneficial for the pilot flying and continued reading out loud the key flight parameters until touch down. This finding would suggest that, during their visual approach, the JCS was able to adapt and find the necessary resources to meet the challenges brought about by the new artefact (the headset).

Another interesting example in the other direction was the report from crew 4. The captain reflected on his effort to cope with the blurriness of vision, when using the headset: "You had the feeling that, never mind the FMS, let's just fly the aircraft ... but later, in practice it turned out to be really difficult, flying and relying on your [passthrough] vision." Arguably, this could be interpreted as not investing in coordination devices and common ground beforehand, which led to a higher workload through increased coordination costs later during the visual approach phase. This is reflected in the crew 4 Bedford scores as

well. Figure 9 summarizes the researcher's synthesis of the challenges faced by the crews stemming from the use of the headset, in a tabulated form.

Figure 9

Summary of challenges faced by the crews.

Visual distortion effects
Headset visual was blurry
Aircraft displays were harder to read
Colours were harder to distinguish
Dual synthetic visual was troublesome
Flickering simulator visual
During visual approach, visual was tearing and wobbly
Switching gaze inside/outside cockpit made the visual wobble and shake

Impaired head-gaze coordination
Gathering of information was harder
Head was oriented more downwards than normal, because of limited FOV
Instead of just shifting the gaze like normal, head movement was required
Head movement made the visual blurry, making it hard to read text/parameters
After head movement, there was a small delay when the visual came back to focus again
More need for head turning, while simultaneously needing to keep the head still

Reduced scan efficiency
Delayed focus after head movement slowed down instrument scanning
Cross-scanning and basic instrument scanning pattern inefficient
Confirmation of the inputs more often and in a more explicit fashion
A need to double-check inputs
Disrupted hand-eye coordination during manual flight

Degraded non-verbal communication
Not able to see what the other pilot is doing
Expressive behaviour and facial cues of the other pilot were missing

Communication inefficiency
Amount of communication increased
Efficiency of communication decreased
Production of communication was slower

Increased cognitive workload
Increased focus
Reduced capacity
Small things took more time to accomplish
Same outcome needed more effort
Increased workload

Discussion

"It was like a veil of fog between our coordination ... like our physical distance had grown larger."
Captain, crew 5

The scenario design was arguably proven successful, keeping the exploratory objectives of the study in mind. While limited by available resources and scope, the scenarios with their different phases and airports provided ample material for the researcher to observe, and for the crews to experience and reflect upon. There was more focus on the pilots and the organizational artefacts such as communication, procedures, roles and task sharing, rather than on the technological elements of the existing aircraft systems. Had there been more time and resources, additional crews could have provided more interesting data for the study, i.e., saturation was probably not achieved with only 5 crews using headsets. With more crews, it might have been plausible to conduct the study as an experimental design, although it would have been a completely different study. More time could have also enabled the implementation of further theoretical replications with a different headset. Crews using a high-performance headset, like the Varjo XR-4, could have revealed very interesting differences between the crews who were using the Quest 3. Nevertheless, this study was still able to explore the technology's impact on coordination in meaningful and revealing ways. Next, we will explore these and try to answer our research question: how does using passthrough video for vision influence flight crew coordination?

Crew members looking at each other

One of the theoretical propositions coming into the study was that because the headset has a reduced field of view and it obscures facial features, it affects how the crew coordinates their work in a JCS. This was explored through observing how the pilots look at each other and establish eye-contact, and through their self-reflection during interviews. Creating a synthesis from the tabulation (see figure 6 and 7) and the interviews, enough evidence was accrued to argue that the headset indeed affects how crews turn their heads and look at each other, as initially proposed. Although, it should be remembered that the eye-contact was inferred when the crew had the headset on, as discussed in the analysis section previously. In line with what Hollnagel & Dekker (2024) wrote, this artefact was not a value neutral addition into the

JCS. For most pilots (Phase 1: 9 out of 10, Phase 2: 8 out of 10), using the headset meant that they looked at the other pilot less frequently overall, and also in those instances where the other pilot was already looking at them (reciprocation). As mentioned earlier, less reciprocation was expected because of the reduced FOV, but the effect could be mitigated in those situations where the other pilot invites eye-contact by talking at the other pilot, creating an audible cue. The findings also indicated that the headset induced more workload and made the pilots' actions and reading slower, having them focus more on the displays, instruments, buttons and knobs. It would thus make sense, that having to exert more effort and focus elsewhere would leave less time to turn your head and look at the other pilot. In addition, looking at the other pilot might bring you less benefit, because of their obscured facial cues.

Despite this, some pilots reported that they didn't mind not seeing the other crew member that much. This was supported by observations, where it was evident that some pilots preferred to look at the other crew member a lot more often compared to others. This research design was not geared to uncovering these reasons that might be because of personal preferences, styles of working, previous familiarity or maybe due to social or cultural aspects. However, why it might be possible to have these contrasting personal differences (of looking at the other crew member) can be explained at least in part with schema theory and coordination devices. The SOP as a coordination device is by definition very standardized, includes specific callouts and also acts in itself as a tool for verbalizing the work being done and to be done on the flight deck. It is designed in a way that strongly supports keeping your visual focus on the displays and instruments while guiding pilot interaction through verbal cues. The SOP also supports anticipation with detailed task sharing and roles. The standardized way of doing things reinforces pilot schemata and how they expect the flight to progress, and what to happen next. Just like the buttons and knobs can be found with 'muscle memory', the standard flow of the operation makes it possible to conduct task sharing and coordination without even seeing the other pilot. As crew 3 noted, if the other pilot is following SOP, you don't really need to see what they are doing. While the coordination devices and strong schemata help pilots conduct work with less visual contact between them, context also matters. As found in this study, there were dramatic differences between phases (1 & 2 vs. 3). In the manual flight portion of the visual approach, no crews looked at each other even once, with or without the headset.

Phases 1 and 2, on the other hand, showed that having SOP does not mean that the visual contact has no purpose for joint activity. What *were* the situations where eye-contact mattered then?

Earlier in this thesis, procedures were described as coordination devices, but their substance is not uniform. Some are more straightforward and strict, such as abnormal procedures for well-defined malfunctions. Others are more general and have built in leeway, such as the approach briefing template. All of them can be divided into phases, and between these phases inside the prescribed procedures, there can be found space and time for unprescribed behaviour. As was described in the findings, it was in these spaces between the prescribed behaviour, where the eye-contact seemed to matter and where it was observed to be sought out the most. These spaces did not have the standard callouts or standard behaviours available. These were the spaces where the crews had to stop and think about their next move or decide something together as a crew. It was for building and maintaining common ground (Klein et al., 2005). As the captain of crew 1 was said in a quote earlier, eye-contact was a signalling device for seeking and creating mutual understanding. Building and maintaining common ground is a coordination cost in one place to mitigate coordination costs later in other places. Neglecting the maintenance of common ground creates potential trouble for later and risks the possibility for a breakdown in joint activity. For example, not investing enough in the briefing part of the approach (i.e., building common ground) and leaving things open, might backfire during the approach with increased need to verbalize intended actions and plans (i.e., coordination costs) when the workload is higher and tempo of events quicker. Arguably, this was seen during the phase 3 portions of this study, where crews no longer looked at each other and had their focus on executing the approach as briefed and following tightly the prescribed procedures, with either no capacity or no need to build common ground through eye-contact. This view is also supported by the reflections of the captain of crew 4, where he recalled during the interview that his failure to invest enough effort into programming and briefing the FMS properly (i.e., the coordination devices and common ground) created more trouble and workload later during the approach.

A rival explanation for less head turning, eye-contact or reciprocation would simply be because of a learning effect. The scenarios were similar by design, so one might argue that the second scenario (with the headsets) would have needed less eye-contact or elements of agreement between the pilots, i.e., less maintenance of common ground. With the evidence available, this effect cannot be ruled out, but the

interviews build a strong argument against such a simple answer. Crews reporting lower situation awareness, increased workload, detrimental effects to communication and feelings of loneliness suggest a lot more is going on here. Maybe one could device of such a scenario, where the need for eye-contact would increase, when using a headset?

Having the crews come from the same company with a relatively similar background was both a benefit and a handicap for the study. Homogeneity probably made some features of their behaviour more salient, while hiding others. What if they were international crews from different companies and different cultural backgrounds? What if some of the pilots were more inexperienced? It is not a far fetch that these qualities could have an impact on the results. As Orasanu-Engel & Mosier (2019) note, establishing a positive climate is important for effective teamwork, thus it is unclear what kind of effect a headset that obscures important facial cues would have on it, especially with culturally diverse crews. Future studies could focus more on the verbal and non-verbal communication aspects of using a headset on a flight deck. Also, incorporating additional data sources such as video recording and eye-tracking data from the headset could result in more interesting findings relating to crews looking at each other.

Choreography of joint activity

The other key theoretical proposition was, that the headset would slow down routine actions that crew members take and that this would incur coordination costs and increased workload. One possibility was, that this would come about by the crews having to turn their heads more, but as was found out, it was more complicated than this. It quickly became apparent that most of the effects to signalling, phases, coordination costs and workload could not be deduced from the observations alone, and the study would have to rely heavily on the interviews.

As discussed about in the literature review, these headsets with passthrough displays have many technical aspects that affect how the visual looks for the user. Some of these include resolution, refresh rate, frame rate and input lag. Many of these aspects were probably affecting the experience of the crews and how they reported it, but it was beyond the scope of this study and would have also been difficult to try to differentiate these effects from each other in this context and with this research method. For example, many crews attributed the blurriness of their vision to the lower resolution of the Quest 3, but it could have also been due to refresh or frame rate issues, if their head was in motion. Hence, two clear

handicaps of this study, that could have been fixed with another setup rather easily, were resolution and screen flicker. The resolution of the Q3 made reading smaller texts more time consuming (you had to lean forward) and the flickering simulator visual made it more difficult to look outside the aircraft. Regardless, the focus is not on what specific technical parameter was behind this or that experience, but in the crew experience on how the work being done was changed by the headset, especially from a coordination perspective. This is because even though the magnitude of various effects varies from device to device, arguably same generation devices still have similar technological underpinnings and limitations. Thus, this exploratory study gives valuable information on what aspects to consider when exploring future devices from a crew coordination perspective.

Blurriness of vision

The findings, mainly from interviews, indicate following things related the blurriness of vision and head movement. When there was no head movement, the vision was blurry, but manageable. This made reading and seeing text and parameters slower, and sometimes the pilots had to lean forward to see more clearly, e.g., when looking at displays further away in the central pedestal. If the pilot started to move their head when their gaze was fixed to a target, the vision became even more blurry, with some crews reporting of other distortions such as tearing and twitching, as well. When exploring their peripheral visual field, humans often first move their gaze followed by appropriate head movement in the same direction, but it is also common to have the head movement occur with smaller gaze adjustments (e.g., Hooge et al., 2024; Fang et al., 2015). This would suggest that inside a flight deck, even when switching to targets that are within the FOV of the headset, it would often be accompanied by small head movements that would create additional blurriness. Reports indicated that after stopping head movement, there is also a small delay before the visual comes to focus, meaning additional time spent looking at the target. Thus, the situation in this study would appear to be that, on the one hand the pilots wanted to keep their heads still as much as possible, but on the other, had the natural habit of following their gaze with small head movements.

Keeping your head still to focus on a target would make reading of the text or parameter slower. If you had to move your head before acquiring the target, there would be the added delay of waiting for the text to come in focus. Reduced FOV would probably increase the number of head movements, thus

increasing the instances where seeing or reading is slower. Phase 3 with its visual approach, would have the pilots turn their heads quite often between the outside view and inside the flight deck. This would further exacerbate the problems described above.

Coordination costs and workload

The findings show that these delays make the phases and signalling of the pilots slower. They also disrupt the normal tempo of doing work, creating more workload and even altering the normal way of doing things. Crews compensated with more communication, additional confirmation of actions and inputs, and by being more explicit. The additional coordination costs were more manageable in the first two phases, but when under time pressure and with increased demands on cognitive resources in the third phase, it became harder to cope with the added workload. Crews reported reduced capacity and higher workload, when flying the visual approach with the headsets. This led to the omission of signals, reported inability to "communicate fast enough", or even "freezing". The increased coordination costs and workload posed a risk for a breakdown in joint activity. At the same time, the crews were still able to adapt to the situation and manage the workload through the use of coordination devices. Briefing thoroughly during the phase with a lower workload meant investing in common ground, which in turn provided more efficient communication and less need for signalling, freeing up capacity for later during the higher workload period. As depicted in the findings section, crew 2 with their on-the-fly adaptation was an example of resilient performance. Overall, the crews adapted and handled the situation variably: some had the PM increase callouts, others relied more on FMS guidance, briefings were different, etc. All crews felt that it was not easy to fly the visual approach, but some reported it more difficult than others. All crews nevertheless handled the visual approach and kept themselves in control. Increasing workload for longer periods of time might be interesting from a fatigue standpoint. The scenarios with the headset lasted around 30-45 minutes, so the fatigue aspects of using a bulky XR headset were not explored here. We know from other research (e.g., Guo et al., 2020), that just wearing a headset induces various levels of fatigue to the user. In our context, increased effort and additional workload (e.g., phase 3) on top of that for extended time periods could be a double whammy from the perspective of fatigue.

The study also found more ambiguous effects of working with the headset, that unfortunately could not be explored further in this study. These were reported during the interviews, where crews

reflected on their experiences, such as coordinating through a 'veil of fog', feelings of loneliness and a greater distance between crew members, feelings of uncertainty and even effects to hand-eye coordination during manual flight. Future studies with different research designs could be in a better position to study these.

Future potential

The potential of mixed reality is using it outside the full flight simulator, leveraging the use of virtually added elements. The FFS is expensive to acquire and operate, and if organizations can attain similar or at least adequate levels of fidelity with a cheaper head-mounted device paired with an FTD, it could mean more available training hours for pilots.

As this study suggests, using a headset just for the passthrough vision arguably brings no additional benefit for the crew. The real potential of mixed reality is with the virtually added elements that are overlaid and mixed with the 'real' world. The low hanging fruit consists of replacing existing elements with cheaper virtual versions, such as aircraft displays and the view outside the aircraft. More interesting, however, is the potential for novel training solutions not previously possible. These could be virtual elements that increase the awareness of what the other pilot is doing (e.g., gaze tracking 'lasers' and virtual pointers), bring specific cues or instructions to the user’s field of vision, or 3D visualizations of approach charts and flight paths for the crew to use during briefing. All these could be beneficial for building and maintaining common ground in joint activity.

The author suspects that using a virtual avatar, instead of being co-located with and seeing the other pilot, would not diminish the 'veil of fog' between the coordination among the pilots, probably the opposite. However, if it could be shown that training in mixed reality using a virtual avatar offers reasonably good fidelity of coordination compared to actual line flying operations, it would remove the need for the pilots to be situated in the same physical space. This could make the logistics of training crews more flexible and enable training organizations to further increase the amount and quality of training. For ab initio or initial training, where the focus is on learning the procedures and aircraft systems, the virtual avatar could be an adequate representation of the other pilot, whereas in recurrent training with experienced crews it might not be sufficient.

The danger is, that with a shiny new toy having new technological capabilities, the JCS perspective of work gets forgotten. If the goal is to prepare pilots to work safely and efficiently in line flying operations with actual aircraft, these new head-mounted training devices should not ignore the subtle nuances and choreography of joint activity. If working as a crew is different with a headset in an FTD compared to a real aircraft, the training syllabus should acknowledge and reflect this reality. How should an ab initio training syllabus using an XR headset be designed, so that it supports a later transition to an FFS without the headset? If the student learns that it's not beneficial to seek eye-contact with the other pilot during early training, will they retain that behaviour later when seeking eye-contact might be advantageous instead?

Conclusion

Conclusion of the study comes with a reminder, that context is important. The probable use case of an XR headset would not be in a full flight simulator. This should be kept in mind when interpreting the findings. Problems with the blurriness of vision; because of low resolution, refresh rate, frame rate, or other technical issues; can be rather easily fixed with better devices that are already available or will be in the very near future. It should also be noted that XR devices would take advantage of virtual additions, such as displays instruments, that would not be subject to issues stemming from the use of passthrough video feed from external cameras, and particularly to issues created by looking at an external simulator visual.

The flight deck proved to be resistant to the effect of not seeing the other pilot in a normal way. Standardized procedures, callouts, roles and task sharing provided robust ways of conducting flight deck work even with reduced awareness of the other pilot and their actions. There were personal preferences, where some pilots found it more troublesome than others. Despite this, findings showed that eye-contact still matters and serves a purpose for building common ground and shared understanding. Non-verbal communication also still plays a role, albeit a more nuanced one than initially expected. Crew climate and social questions could play a role, depending on the context and length of the session.

The headset used in this study (Quest 3) slowed down the actions of the pilots, affecting their signalling and phases. It was left unclear, what exact technical feature created what effect, and so it was usually referred to as just 'blurriness'. Probably most of these technical features could be fixed with a better device, but to what extent? Even if the 'blurriness' and its effects were reduced by, e.g., 90%, would there still be slower signalling and phases? These effects were tightly connected to creating additional coordination costs and workload for the crews. Findings suggest, however, that it was also at least partly because of other effects, besides just blurred out vision. Crews were able to handle the detrimental effects of the headset with effective joint activity and by increasing their effort. But in the end, this study was unable to sort out in detail what affected what, and how much.

Future studies

Future studies should explore how the headset affects verbal and non-verbal communication, especially the role of eye-contact. Discovering the importance of seeing the other pilot could inform the

use of virtual avatars in different training contexts. If using virtual avatars turned out to be plausible, this could negate the need for the pilots to be in the same physical place, unlocking more potential use cases for multi-crew training in XR. Another rather obvious proposition for a later study would be exploring the choreography of joint activity while using a high-end XR device, that has the best available resolution, refresh and frame rates, taking out most of the 'blurriness' that affected this study. The future studies could use external eye-tracking devices to collect data when not wearing the headset (see Knabl-Schmitz et al., 2023), combined with the built-in eye-tracking and video feed data from the XR headset. Using both data sources could reveal interesting patterns and differences in gaze shifts and head movements of the pilots in different scenarios.

This was an exploratory study inspired by case study research. Even with the technical difficulties and limited scope, it is argued that the study was able to explore in a meaningful way how this new technology affects flight crews working on an airliner flight deck. The study was also able to suggest propositions and operational measures for later studies, fulfilling its exploratory objectives.

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Appendix A: Demographics questionnaire form

<u>**In Finnish, as presented to the participants:**</u>

Päivämäärä:

Positio:

Kapteeni / perämies

Ikä:

20-30v / 30-40v / 40-50v / 50-65v

XR tulee sanoista extended reality ja kattokäsitteenä se pitää sisällään termit VR (virtual reality), MR (mixed reality) ja AR (augmented reality).

Aikaisempi kokemukseni XR-laitteiden käytöstä:

Ei kokemusta / Vähän / Jonkin verran / Paljon

Oletko käyttänyt aiemmin XR-laseja, joissa on passthrough video ominaisuus?
Esim. Meta Quest 3, Varjo XR-3/4 ja Apple Vision Pro

Ei kokemusta / Vähän / Jonkin verran / Paljon

<u>**In English:**</u>

Date:

Position:

Captain / First Officer

Age:

20–30 / 30–40 / 40–50 / 50–65

XR stands for extended reality and, as an umbrella term, encompasses VR (virtual reality), MR (mixed reality), and AR (augmented reality).

My previous experience with using XR devices:

No experience / Limited experience / Some experience / Extensive experience

Have you previously used XR headsets with passthrough video capability?
For example, Meta Quest 3, Varjo XR-3/4, or Apple Vision Pro

No experience / Limited experience / Some experience / Extensive experience

Appendix B: Classroom briefing

Briefing

Overview of the research project

Who am I

What is this about

Remuneration

The items in the consent form

Sign the form indicating informed consent

A short demographics questionnaire

Outline of the session

2 scenarios around 45min each

A few phases

2 airports

Captain as PF

Instructions for flying the scenarios

Nothing out of the ordinary

Follow SOP, unless it is necessary to deviate

Just do your normal stuff, that is enough

This is not a LOFT, no roleplay needed with third parties

Your performance is not being evaluated

For the research to be authentic, I'm not saying what it is that I am specifically observing or focusing on

Intro to MR headset

Try it on

Ensure the settings are correct

Try to read the iPad with it

Try to read the QRH with it

Don't press any buttons. Say if something is wrong and I will pause the sim.

Briefing materials

Familiarize the crew with the IAC charts to be used on the company iPad

Update Lido charts, if needed

Split - LDSP - Lido IAC - "Visual 23" - Visual approach with prescribed tracks

Dubrovnik - LDDU - Lido IAC - "Visual 29" - Visual approach with prescribed tracks

Bedford workload scale

Familiarize yourself with using the form

You will answer the form after each phase, individually

Do not talk to each other about your input to not bias yourselves

Appendix C: Simulator setup

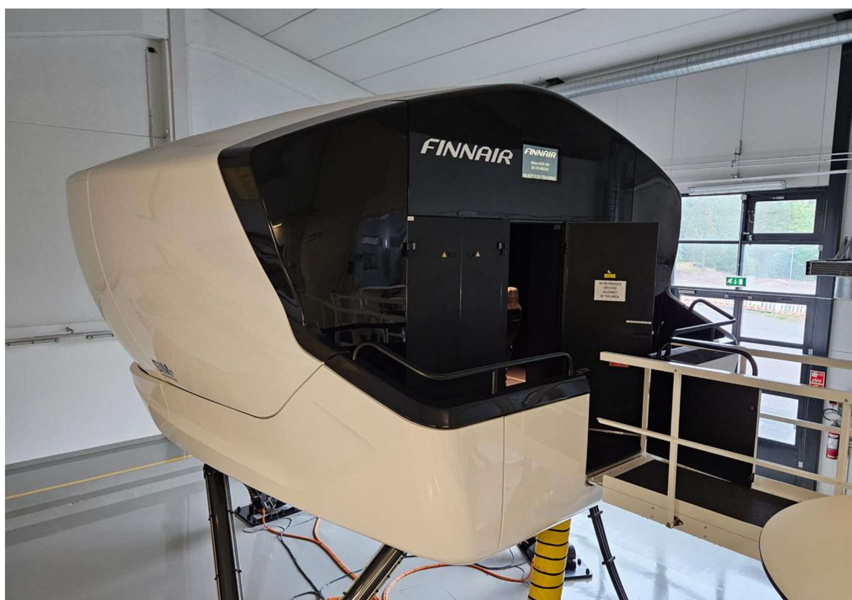
Recording equipment in the simulator:

- Front facing video camera behind the flight crew: Samsung Galaxy S20
- Rearward facing video camera on the glareshield: GoPro Hero Black
- External microphone to record crew voice, on pedestal: Blue Yeti

Recording equipment for the classroom interview:

- External microphone to record voice: Blue Yeti

Pictures of the simulator setup and the Meta Quest 3:



Appendix D: Interview questions

<u>Semi-structured interview</u>

Instructions for the interview

- Answer as a crew, bring out both voices
- Answers will be recorded via microphone

Interview questions (in Finnish, as used in the research)

- Ei pelkästään tänään, vaan yleisellä tasolla: miten kuvailisitte mielestänne hyvää miehistön keskinäistä koordinaatiota ohjaamossa?
- Millä tavoin MR headsetin käyttö tänään vaikutti teidän koordinaatioon?
    - Miten se näkyi lennon eri vaiheissa (brief, häiriö, visual approach)?
- Miten MR headsetin käyttö vaikutti työkuormaan?
    - Miten se näkyi lennon eri vaiheissa (brief, häiriö, visual approach)?
- Kuvailkaa teidän kokemuksianne: millaista oli lentää MR headsetin kanssa tänään. Oliko lentäminen jotenkin erilaista?
- Käyttäen apuna core competencyjä, pohdi muutaman kompetenssin kautta, mitä vaikutusta MR headsetin pitämisellä oli lentämiseen?

Interview questions (in English)

- Not just today, but on a general level: how would you describe good crew coordination in the cockpit in your opinion?
- In what ways did using the MR headset today affect your coordination?
    - How was this evident during different phases of the flight (briefing, malfunction, visual approach)?
- How did using the MR headset affect your workload?
    - How was this reflected in the different phases of the flight (briefing, disruption, visual approach)?
- Describe your experience of flying with the headset today. Was flying with it somehow different?
- Using the core competencies as a reference, consider a few competencies to reflect on how wearing the MR headset impacted the flight.

Appendix E: Form for informed consent

Consent form in Finnish that was presented to participants:

Tutkimuksen tarkoitus

Tutkimus on osa Juho Lehtosen pro-gradu tutkielmaa Lundin yliopiston maisteriohjelmassa Human Factors and Systems Safety. Tutkimuksessa tarkastellaan päässä pidettävien lisätyn todellisuuden laitteiden (mixed reality head-mounted device) käyttöä ohjaamoympäristössä. Tutkimusta tehdään yhteistyössä Finnair Flight Academyn kanssa käyttäen hyödyksi XR-SPACE-hankkeen resursseja. XR-SPACE-hankkeeseen voi tutustu osoitteessa https://projects.tuni.fi/xr-space/.

Tutkimusmetodit

Tutkimus koostuu kahdesta osasta. Ensimmäisessä osassa lennetään A330-simulaattorissa kaksi skenaariota. Simulaattorissa tehdyt suoritukset tallennetaan videolle ja myös äänimaailma nauhoitetaan. Tutkimuksen toisessa osassa suoritetaan haastattelu luokkahuoneessa, joka tallennetaan mikrofonilla digitaalisesti ääninauhaksi. Näiden lisäksi tutkimuksessa kerätään osallistujilta suppeat taustatiedot kyselylomakkeella.

Tutkimusaineiston käyttö ja säilytys

Tutkimusaineistolla tarkoitetaan taustatietoja sekä video- ja äänitallenteita, mitä kerätään simulaattorissa ja haastattelussa. Tutkimusaineistoa käytetään ainoastaan Juho Lehtosen pro gradu tutkielmaan. Tutkimusaineisto anonymisoidaan siten, että tutkimukseen osallistuvien henkilöllisyyttä ei voida tutkimuksesta tunnistaa. Tutkimusaineistoa ei jaeta kolmansille osapuolille, kuten esimerkiksi Finnairille. Tutkimusaineisto säilytetään tutkijan henkilökohtaisella kovalevyllä, mihin muilla ei ole pääsyä. Halutessaan tutkimukseen osallistujat voivat saada oman suorituksensa aineiston omaksi nähtäväkseen. Tutkimukseen osallistujilla on myös oikeus pyytää omaan suoritukseensa liittyvän tutkimusaineiston poistoa.

Tutkimuksesta vastaava henkilö

Tutkimuksesta vastaava henkilö on Juho Lehtonen. A330-simulaattorin lainaa käyttöön Finnair Flight Academy ja heitä edustaa Arto Helovuo. Metropolian Helsinki XR Center lainaa Meta Quest 3 laitteet tutkimuksen käyttöön ja heitä edustaa Santeri Saarinen sekä Mikko Höök.

Suostumus

Ymmärrän, että osallistumiseni tähän tutkimukseen on vapaaehtoista. Minulla on oikeus milloin tahansa tutkimuksen aikana ja syytä ilmoittamatta peruuttaa suostumukseni tutkimukseen. Olen tietoinen siitä, että suostumuksen peruuttamiseen mennessä kerättyjä tietoja saatetaan käyttää osana tutkimusaineistoa.

Consent form translated to English, using ChatGPT:

Purpose of the Study

The study is part of Juho Lehtonen's master's thesis for the Lund University Master's Programme in Human Factors and Systems Safety. The research examines the use of mixed reality head-mounted devices in a cockpit environment. The study is conducted in collaboration with Finnair Flight Academy and utilises resources from the XR-SPACE project. More information about the XR-SPACE project is available at https://projects.tuni.fi/xr-space/.

Research Methods

The research consists of two parts. In the first part, two scenarios are flown in an A330 simulator. The performances in the simulator are recorded on video, and the audio environment is also captured. The second part involves an interview conducted in a classroom, which is digitally recorded as an audio file. Additionally, brief background information is collected from participants via a questionnaire.

Use and Storage of Research Data

Research data refers to the background information as well as the video and audio recordings collected during the simulator sessions and interviews. The data will only be used for Juho Lehtonen's master's thesis. It will be anonymised to ensure that the identities of the participants cannot be identified in the research. The data will not be shared with third parties, such as Finnair. The research data will be stored on the researcher's personal hard drive, to which no one else has access. Participants may request access to their own performance data for personal review. They also have the right to request the deletion of data related to their performance.

Responsible Parties for the Study

The person responsible for the study is Juho Lehtonen. The A330 simulator is loaned by Finnair Flight Academy, represented by Arto Helovuo. Meta Quest 3 devices are loaned by the Metropolia Helsinki XR Center, represented by Santeri Saarinen and Mikko Höök.

Consent

I understand that my participation in this study is voluntary. I have the right to withdraw my consent to participate at any time during the study without providing a reason. I acknowledge that data collected up to the point of withdrawal may still be used as part of the research.

Appendix F: Scenario design

Scenario construction specifics

Two scenarios to two airports (Split LDSP, Dubrovnik LDDU)

- One without the headsets and one with them
- Scenario order will be randomized between crews
  - I.e., others will start at Split, others at Dubrovnik. Everyone starts without the headset.

Each scenario has 3 similar phases

- Briefing phase
  - Low workload, no time pressure
    - Approach briefing in a holding pattern using autopilot
  - Crew focus inside flight deck
- Abnormal procedures phase (ECAM actions)
  - Higher workload, low time pressure
    - Still flying in holding pattern with autopilot
    - ECAM advisory condition (ENG high oil pressure or ENG high vibration, using QRH)
    - Followed by ECAM action (ENG flameout or ENG FIRE)
  - Crew focus inside flight deck
- Visual approach
  - Higher workload, high time pressure (event-driven actions)
  - Crew focus inside and outside

Performance, weather and fuel consumption ruled out to limit complexity

- Weather: CAVOK, ISA; Fuel lasts for several hours; Take-off and landing performance given by researcher
- Scenarios not flown in 'LOFT' style, e.g., no roleplay needed with third parties (ATC/cabin crew/OCC)

Relatively complex visual approach profile

- Similar in both airports (see approach charts below)
- Demands attention from both crew members
  - Planning speed/altitude profile
  - Monitoring parameters
  - Dynamic manoeuvring
  - Terrain creating "hard limits", confining the approach
- However, nothing about the approaches is extraordinary or something that requires special training/considerations
- Left hand circuit, captain as pilot flying, having the airport on their side

Scenario script overview

SCENARIO A (without the MR headset)

Quickstart the simulator

PF: Captain, PM: First officer

Warmup: Take-off and establish holding pattern

- Reposition the aircraft on the runway
  - Configure aircraft for take-off
  - Take-off
  - Establish holding

Phase 1: Approach preparation and briefing

- Flying in a holding pattern
  - Familiarization with the instrument approach chart (on iPad)
  - Approach preparations
  - Approach briefing

Phase 2: QRH+ECAM action

- Flying in a holding pattern
  - ECAM advisory condition
    - NAC TEMP > 260 (or similar)
      - QRH procedure
      - When QRH procedure complete
  - ECAM action (triggered by researcher)
    - ENG 1 FAIL (flameout)
      - ECAM actions
      - When engine secured (= Master switch OFF)
  - Conclude phase 2 and reset engine

Phase 3: Visual approach

- When crew ready, leave holding pattern
  - Conduct visual approach with prescribed tracks
  - Configure aircraft
  - Establish stabilized approach criteria
  - Make a landing (or a go around if needed)
- Conclude phase 3 when aircraft stopped on runway

SCENARIO B (with the MR headset)

Don the MR headset

PF: Captain, PM: First officer

Warmup: Take-off and establish holding pattern

- Reposition the aircraft on the runway
  - Configure aircraft for take-off
  - Take-off
  - Establish holding

Phase 1: Approach preparation and briefing

- Flying in a holding pattern
  - Familiarization with the instrument approach chart (on iPad)
  - Approach preparations
  - Approach briefing

Phase 2: QRH+ECAM action

- Flying in a holding pattern
  - ECAM advisory condition
    - High engine vibration
      - QRH procedure
      - When QRH procedure complete
  - ECAM action (triggered by researcher)
    - Eng 1 FIRE
      - ECAM actions
      - When engine secured (= both bottles discharged)
  - Conclude phase 2 and reset engine

Phase 3: Visual approach

- When crew ready, leave holding pattern
  - Conduct visual approach with prescribed tracks
  - Configure aircraft
  - Establish stabilized approach criteria
  - Make a landing (or a go around if needed)
- Conclude phase 3 when aircraft stopped on runway

Postflight phase

- Quick postflight procedures
- Shutdown and secure the aircraft

Approach charts, Split (LDSP) & Dubrovnik (LDDU)

Visual 23

ATIS 125.300
TWR 124.675 118.100

Caution
Maintain visual to RWY 23.
SPL VOR for additional information only.
Obstacle clearance during the visual approach and visual go-around is responsibility of pilot flying.

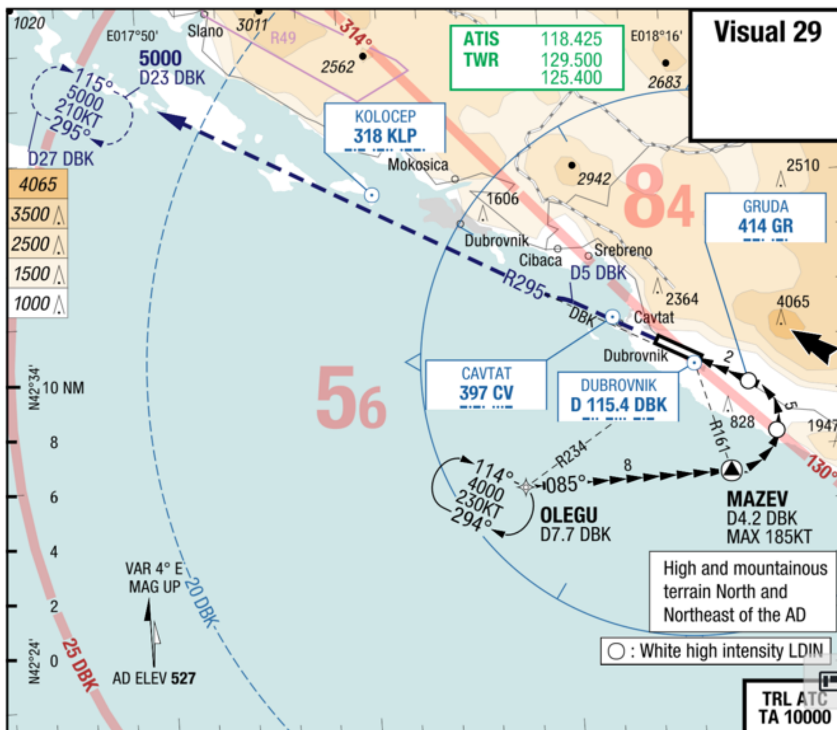
High and mountainous terrain north and northeast of the AD.

VAR 4° E
MAG UP
AD ELEV 78

TRL ATC
TA 10000

VISUAL

Missed Approach:
Once on FAT:
direct DVN
climb 3000



VISUAL

all red, LED Lights

60 HL

30 HL — 45 x 3230

3.2°

420

29

+0.3% TDZ --- (---%) / **THR 485** (18hPa) L-S

ATTENTION:
Prominent transmission lines data not complete! No guarantee or the completeness and accuracy of obstacles!

Missed Approach
Straight ahead
at D5 **DBK** intercept R295 **DBK**
to D23 **DBK**
climb **5000**
If unable to reach **5000** at D23 **DBK**, contact ATC.

CAUTION:
Visual APCH track to the RWY29 to be used by means of visual reference only. **DBK** radials, waypoints, distances and speed limit information are for improved situational awareness only. Obstacle clearance during the visual APCH and visual go-around is responsibility of pilot flying.