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16. Abstract

This study documents a baseline of casual and contributing factors to flight deck task management deficiencies and vulnerabilities in flightpath monitoring, and air traffic interactions which affect flightpath management. Sixty-one semi-structured interviews were conducted with participant backgrounds ranging from captains, first officers, check pilots, training personnel and other individuals familiar with flight deck task management primarily in Part 121 or similar Part 135 operations. Participants worked for domestic U.S. operators, or European based operators. The study found several human factors contributing to task management deficiencies and vulnerabilities including interruptions, disruptions, distractions, communication, time management, pressure, taskload, task saturation, task allocation, fatigue, stress, individual differences, international ATC, system complexity, and operational complexity. Six categories of mitigations were identified related to communication mitigations, policies and procedures, prioritization strategies, metacognitive strategies, strategic and tactical strategies for organizing tasks, and training. However, these mitigations do not fully address the impact of high workload and stress on task management. While participants perceived some mitigations to be effective, gaps remain in providing comprehensive task management strategies, especially for high workload conditions, and methods to effectively train task management. Next steps should include (1) explorations of training opportunities to strengthen current mitigations, including development of skills needed for effectively executing task management strategies, (2) exploration of potentially new mitigations for stress and fatigue, and (3) validating the relative importance and relationships of the factors identified in this work, as the factors identified did not occur in isolation but were interconnected and related to one another.

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Final Report

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CONTENTS

ACRONYMS

AC	Advisory Circular
ANCS	Aviate-Navigate-Communicate-System
ATC	Air Traffic Control
CBT	Computer-based Training
CRM	Crew Resource Management
FMS	Flight Management System
FPM	Flightpath Management
GA	General Aviation
ILS	Instrument Landing System
MaxQDA	Max Weber Qualitative Data Analysis
NTSB	National Transportation Safety Board
NTSC	Indonesia National Transportation Safety Committee
PRISMA	Preferred Reporting Items for Systematic reviews and Meta-Analysis
TCAS	Traffic Alert and Collision Avoidance System

EXECUTIVE SUMMARY

This report investigates the complexities of task management among flight crews. It aims to identify the causal and contributing factors to task management deficiencies and vulnerabilities in commercial aviation, document existing mitigations, and determine the perceived effectiveness of existing mitigations. This work answers three research questions:

1. What are baseline causal and contributing human factors to task management deficiencies and vulnerabilities in domestic and international operations?
2. What mitigations have been applied domestically and internationally for task management deficiencies and vulnerabilities?
3. How effective are mitigations that have been applied domestically and internationally?

To answer these questions, a hybrid literature review and systematic review was conducted. A search of twenty-six databases resulted in 13,774 articles. Of those, 544 were deemed relevant. From this literature review, open questions regarding causal and contributing human factors to task management deficiencies and vulnerabilities were identified.

These open questions were used to conduct semi-structured interviews with sixty-one line pilots, check pilots, flight training instructors, and other aviation personnel. Participants were pilots for a Part 121 operator or a Part 135 operator conducting two-person flight operations; single pilot operations were excluded. From the interviews, causal and contributing human factors to task management deficiencies and vulnerabilities were extracted. These factors do not occur in isolation but are often related, and include:

1. **Interruptions and Disruptions**: Interruptions can impact pilot workflow, disrupt tasks, and affect task performance. A broad range of operational factors can intensify the impact of interruptions and the effects on task completion. Interruptions include pauses in a task, activity, or workflow due to communications from other flight crew, cabin crew, gate operators, dispatch, ground crew, and air traffic control (ATC), environmental conditions, malfunctions, and failures. ATC interruptions during critical phases of flight (e.g., landing, emergencies) can overload pilots, leading to task shedding and mismanagement. The strategies pilots use to handle these interruptions vary, which may contribute to task management deficiencies and vulnerabilities.
2. **Distractions**: Operational distractions can impact attention allocation and mental effort towards flightpath management (FPM) tasks. For example, social conversation can divert pilots from tasks and result in dropped tasks or short cuts to tasks (e.g., abbreviated briefings, missed instructions). Some distractions can be linked to complacency, as pilots may engage in social conversation when they feel overly confident or familiar with a situation.
3. **Complacency**: Pilots may become overly comfortable with tasks due to familiarity with certain procedures or situations, leading to reduced attention to detail. This can result in tasks being shortcut or neglected, affecting task management, FPM, and adherence to approved procedures.
4. **Communication Effectiveness**: Verbal exchanges that are clear, concise, consistent, and understandable support safe and effective task management. Communications that are not clear, concise, consistent, and understandable and are poorly timed and reactive can lead to misunderstandings, poor task allocation, and a breakdown in shared mental models among crew members, impacting task management.
5. **Time Management Effectiveness**: Pilots may have varying perceptions of the time they need to complete tasks or the time available to complete tasks. This can lead to rushing, poor planning, and other task management deficiencies. Operational and social pressures can exacerbate these issues by creating a sense of artificial urgency.
6. **Taskload, Task Saturation, and Operational Complexity**: Increased operational complexity can come from a number of factors including operating in congested airspace, managing changing

situations such as when encountering severe weather conditions, and handling unexpected events such as diversions and emergencies. Operational complexity can lead to more pilot tasks and affect sequences of tasks as the situation changes, impacting taskload and potentially leading to task saturation. Pilots may unintentionally shed tasks or lose situation awareness, contributing to deficiencies and vulnerabilities in task management and deviations from an intended or planned flightpath.

7. **Task Allocation**: Task allocation can redistribute workload among crew members; in some cases, it can contribute to an imbalance. More experienced pilots may take on additional tasks to support less experienced pilots, but this can result in task saturation for the more experienced pilot, which may contribute to task management deficiencies and vulnerabilities**.**
8. **Fatigue and Stress**: The impact of fatigue and stress on pilot performance can impair a pilot's ability to manage tasks. As fatigue and stress increase, pilots may become more prone to task shedding and susceptible to task saturation, which can lead to task management deficiencies and vulnerabilities.
9. **Personality Differences**: Variations in personality traits, social behavior, and work styles among crew members can lead to differences in how tasks are managed. These differences can affect crew coordination, adaptability to unexpected events, and contribute to task management vulnerabilities.
10. **International Operations**: Differences in ATC procedures, phraseology, language, and expectations between international and domestic operations, where international operations refer to U.S. based pilots operating in non-U.S. airspace and domestic operations refer to U.S. based pilots operating in U.S. airspace, can create confusion, decrease situation awareness, and increase taskload, contributing to task management deficiencies.
11. **System Complexity**: The design and operational use of modern aircraft systems and enabling avionics equipment can impact the amount of time, steps, and mental effort to complete FPM tasks. For example, programming and sequencing errors in the flight management system (FMS) can cause pilots to lose situation awareness, shed tasks, and deviate from the flightpath.

Six categories of mitigations for task management deficiencies and vulnerabilities were identified and include:

1. **Effective Communication**: Procedural and task-based communication can reduce task management deficiencies, decrease stress and workload, and support the building of shared mental models. Social conversation, when appropriate, can also mitigate deficiencies by building rapport and fostering a communicative environment.
2. **Policies and Procedures**: Appropriate adherence to standard operating procedures can help mitigate several factors contributing to task management deficiencies and vulnerabilities. Mitigations include standardized language, clear task division, confirmation of flightpath changes, and policies that prevent rushing. However, procedures for handling interruptions during normal operations are not consistent; such procedures could potentially mitigate related task management deficiencies and vulnerabilities.
3. **Prioritization Strategies**: Strategies such as Aviate-Navigate-Communicate-Systems (ANCS) are effective for high-level task prioritization. Other strategies include staying ahead of the aircraft, threat evaluation, and setting personalized reminders based on habits, such as using light switches as indicators of tasks completed. Task shedding, while mentioned, is not commonly used as a conscious strategy.
4. **Metacognitive Strategies**: Metacognitive strategies, such as the Green-Yellow-Red workload recognition framework, can help pilots manage task saturation and prevent overload. However, pilots need self-awareness to exercise this strategy, and self-awareness can be challenging to maintain during high workload situations. “Making time” is another metacognitive strategy that can help with managing tasks. Using this strategy means pilots have a strong sense of time and

the ability to recognize when their personal time needs may not align with the time available. Differences in task execution time between crew members must also be considered. Some pilots use the Swiss Cheese model as a conceptual framework for identifying potential errors and assessing mitigations. These pilots hold assumptions about catching errors, such as having a second qualified crew member on board can be a potential mitigation for recognizing and trapping potential errors.

5. **Strategic and Tactical Strategies**: Pilots use a combination of proactive (strategic) and reactive (tactical) task management strategies. Understanding when and how to apply these strategies is crucial but not always consistent across different pilots.
6. **Training**: Because operationally relevant training scenarios are possible in simulators, simulator training can be highly effective for developing task management skills, allowing pilots to practice strategies and build time awareness in a controlled but operationally relevant environment. However, simulator environments have limitations; they may not fully replicate real-world complexities, meaning pilots may not always train and practice adjusting task management strategies as they may actually need to do in the real-world as a situation changes.

Based on the causal and contributing factors to task management deficiencies and vulnerabilities and insights into existing mitigations and pilot perceptions on their effectiveness, mitigations do not fully account for the impact of complex operational environments introducing high taskload, fatigue, and stress on task management. In addition, while participants perceived some mitigations to be effective, there are gaps in effectively applying task management strategies, especially in high workload conditions, and methods to effectively train task management. Next steps and future work should focus on three areas: (1) explorations of training opportunities to strengthen current mitigations, including development of metacognitive skills that can help with applications of task management strategies, including time perception and time awareness, improving briefing techniques, and exploring potential alternatives to simulators for accelerating development of task management proficiencies, (2) improved or new mitigations for stress and fatigue, as these factors impact task management but current mitigations are minimal, and (3) validating the relative importance of the factors identified in this work, given that they are interconnected and frequently co-occur. This last next step would ensure future work focusing on mitigations can be directed and optimized.

1. INTRODUCTION

Flight deck task management is a complex activity involving task prioritization, task allocation, strategic planning (e.g., anticipating and preparing for future flight phases), tactical organization of tasks in response to real-time events, execution, and dynamic adaptation, all while balancing workload and avoiding task saturation. Task management is critical to safe operations, and task management deficiencies, when a pilot does not effectively organize, prioritize, or execute tasks, have been cited as causal or contributing factors in incidents and accidents (Dutch Safety Board, 2010; NTSC, 2018; NTSB, 2019). Attempts have been made to understand some of the causal and contributing factors to task management deficiencies, including how pilots prioritize tasks, manage taskload, respond to distractions and interruptions, perceive, and manage time, and allocate tasks among the crew. Known factors include that operational and time pressures can lead to workarounds or shortcutting of procedures, which can harm task management, and that current task management strategies such as Aviate, Navigate, and Communicate may not adequately account for the complexity and myriad of tasks pilots need to perform in certain contexts, contributing to challenges prioritizing tasks (PARC/CAST, 2013). However, there are more underlying causal and contributing factors to task management deficiencies as well as potential causal and contributing factors to task management vulnerabilities than what have been captured in prior work. Task management vulnerabilities are potential weaknesses in the process of organizing, prioritizing, and executing tasks which then may lead to task management errors.

This work seeks to provide insight into potential flight deck task management deficiencies and vulnerabilities in current operations. In addition, this work seeks to understand any mitigations that may exist and their perceived effectiveness. Three research questions are posed:

1. What are baseline causal and contributing human factors of task management deficiencies and vulnerabilities in domestic and international operations?
2. What mitigations have been applied domestically and internationally for task management deficiencies and vulnerabilities?
3. How effective are mitigations that have been applied domestically and internationally?

To answer these questions, an extensive literature review was first conducted, which highlighted the complexity of task management and a wide range of potential human factors considerations. The literature review was a hybrid literature review and systematic review and involved a search of twenty-six databases, resulting in an initial 13,774 articles. Of those, 544 were deemed to be relevant. These articles were reviewed for insights into task management with a focus on air transport primarily and insights from general aviation (GA) and other similar domains (e.g., controllers) included as additional support.

The results from the literature review were used to support the design of a qualitative study to explore the three research above. The study consisted of sixty-one semi-structured, contextualized interviews with line pilots, check pilots, flight training instructors, and other personnel. The line pilots and check pilots were employed by a Part 121 operator or a Part 135 operator conducting two person flight operations; single pilot operations were excluded. The other personnel could be line pilots or check pilots, but they were also individuals who held some other position in the commercial aviation industry which may provide them with unique insight or knowledge into task management deficiencies, vulnerabilities, and mitigations, for example, flight training designer or director of flight training. Interview responses were analyzed to gain a deeper understanding of task management deficiencies and vulnerabilities, mitigations, and perceived efficacy of mitigations. While there are differences between deficiencies and vulnerabilities, the analysis combines these two factors with the results considering causal and contributing factors as well as mitigations that apply to one or the other or both.

The rest of this report is organized as follows. The next section provides a summary of the literature review; the full literature review is included in Appendix A. Section 3 describes the method taken for the interviews, participant recruitment, design of the interview questions, how the data was collected, and a description of the data analysis process. Section 4 provides a breakdown of the demographics of the participants. Section 5 describes the baseline and contributing human factors to task management deficiencies and vulnerabilities based on the interview responses. Quotes from interviewees are provided. Please note that information contained within brackets in provided quotes (e.g., [ ]) is supplementary explanation to facilitate understanding of the context of the quote. Current mitigations and their effectiveness as gleaned from the interviews are then described in Section 6. Section 7 provides a deeper discussion of these results. The report concludes with potential next steps on how to validate these baseline findings.

2. LITERATURE REVIEW

A hybrid of a literature review and a systematic review was conducted to capture the current state of task management based on what has been presented in journals, conference papers, news articles, incident and accident reports, and other publications. Traditional literature reviews summarize and present overviews of current and historical knowledge derived from a body of literature (Aromataris & Pearson, 2014). However, traditional literature reviews are typically not exhaustive, provide an unsystematic narrative review, and when performed in the traditional sense, can be at risk for bias or systematic error. They can also be difficult to reproduce. In contrast, systematic reviews can be leveraged in fields where the volume of available literature grows at a phenomenal rate. Systematic reviews aim to provide comprehensive, unbiased synthesis of many relevant studies with a documented methodology (Wright et al., 2007). This work utilizes a hybrid-method in that attempts are made to make the search exhaustive, provide a transparent systematic methodology that can be replicated, while allowing narrative review to assess the quality of the collected literature. To structure the identification and search of relevant articles, Preferred Reporting Items for Systematic reviews and Meta-Analysis (PRISMA) literature review guidelines were followed (Liberati et al., 2009). The flowchart for this review can be found in Figure 1.

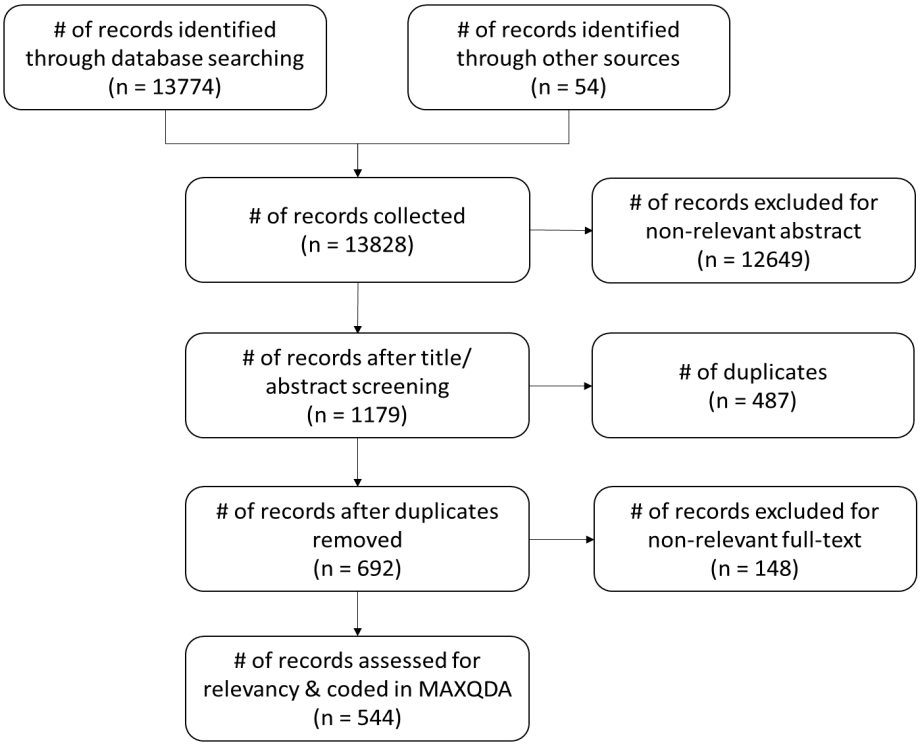

Figure 1. PRISMA flowchart for literature review

The complete literature review can be found in Appendix A. The complete review includes a listing of the research questions and key terms used for the search, the databases searched, the relevant records, and how insights were extracted. Several take-aways are described below; see the full literature review for additional findings, details, and references. These take-aways informed the questions that were posed in the interviews; results from the interviews expand upon the causal and contributing factors below and provide insight into other causal and contributing factors as well as potential mitigations.

If there were a single take-away from collection of 544 articles reviewed, it would be that effective task management involves many components and is complex. In addition to task prioritization, task allocation, strategic planning, tactical organization of tasks, task execution, and dynamic adaptation, the literature review highlighted task shedding, task initiation, task termination, effects of individual differences, system design, environment, and the role of communication. Deficiencies such as improper prioritization, inappropriate shedding of tasks (e.g., dropping the monitoring task), and the inability to adapt to unexpected situations can stem from a combination of high workload, task saturation, improper application of task management strategies, attentional tunneling, fatigue, stress, and/or over-reliance on automation.

Existing literature on task prioritization alone is extensive. Task prioritization is commonly associated with the comparison and selection of tasks to form an ordering or ranking to which attentional resources will be allocated relatively (Bishara, 2002; Chou & Funk, 1990; Colvin, 2000; Colvin et al., 2005; Funk, 1997; Funk & McCoy, 1996; Hoover, 2008; Leedom & Simon, 1995; Parasuraman & Rovira, 2005; Stebel, 2005). Aviate-Navigate-Communicate-Manage Systems (ANCS) is a common prioritization strategy used by pilots. However, applying ANCS can be challenging when pilots have a complex task environment, such as during an emergency. Even when guided by a strategy, prioritization can be subjective, requiring judgements and decisions based on knowledge, skill, and experience. Prioritization can be influenced by factors such as perceived threat, workload, and individual differences (e.g., experience, culture, working memory), and there is evidence that task prioritization may only be partially conscious with some aspects of task prioritization potentially occurring unconsciously. The interviews explored in greater depth potential causal and contributing factors to misprioritization, how prioritization strategies may mitigate task management deficiencies and vulnerabilities, and any opportunities or gaps related to task prioritization.

The literature review indicated that when pilots experience high taskload and are task saturated or overwhelmed by the number of tasks they need to perform, they may shed or abandon tasks to focus on the most important ones. Task shedding can be challenging as the pilot must make quick decisions about what to shed. When task saturated or overloaded, they may shed tasks inappropriately or even unconsciously. A robust prioritization strategy can help pilots make the decisions about which tasks to keep and which to shed; proficiency in metacognitive skills such as self-awareness and time management may also be mitigations. The interviews sought to highlight in more detail causal and contributing factors to task shedding and potential mitigations.

Procedures support task management by providing a task management framework, including tasks to complete, prioritization of tasks, allocation of resources, scheduling of tasks, managing of interruptions, and guidelines for communication. However, procedures can also add taskload depending on the context in which the procedure is applied. For example, other flight critical, concurrent tasks may add taskload on top of procedure taskload. Further, pilots may need to shed procedural tasks depending on the situation, and procedures need to allow for this. Repetition of procedures may also lead to complacency and short-cuts; pilots may be unaware of that their performance has degraded. The interviews built on these findings by exploring pilot perspectives on procedures and potential causal and contributing factors to task management deficiencies and vulnerabilities related to procedures.

Fatigue and stress impact task management by reducing cognitive resources, leading to effects on attention, memory, and decision making. The literature review suggests that pilots may be trained to recognize the

signs of fatigue and stress, but there also may be other mitigations that can help manage the effects of stress and fatigue on task management. The interviews focused on capturing additional narratives in context where fatigue and stress may affect task management to understand potential mitigation opportunities.

Finally, the literature review emphasized the importance of mental models for task management. Mental models are representations an individual forms in their mind of how they expect the external world (e.g., the aircraft, systems, environment) to behave (Holder et al., 2024). Pilots generate expectations of how they expect a flight to proceed, forming a mental model they update over the course of the flight (Billman et al., 2020). Shared mental models are shared representations among more than one person, such as among a team. Shared mental models allow team members to select actions that are consistent and coordinated with those of their teammates (Mathieu et al., 2000). For example, the pilot flying and pilot monitoring have a shared mental model of the aircraft state; they may update this shared model when one pilot makes a change to the aircraft state, such as engaging autopilot. Mental models and shared mental models are used to manage tasks, particularly the strategic planning and the tactical (re-)organization of tasks.

Mental model mismatch occurs when a mental model of a system or situation does not adequately describe how the system or situation is behaving or proceeding (Baxter, Besnard, & Riley, 2007). For example, a pilot's mental model of how they expected the flight to proceed may not align with how the flight is actually proceeding (e.g., ATC vectors the aircraft off the arrival). In two-person flight operations where two pilots are working together, one pilot's misaligned mental model may disrupt the shared mental model. Misalignment can arise from differences in training, experience, perceptions, or interpretations of information and can potentially contribute to task management deficiencies. The literature review suggests that mismatches can compromise situation awareness, delay decision-making, and may lead to errors in executing tasks, as each party operates under a different set of assumptions and expectations. For instance, a pilot may assume they can accept a certain clearance from ATC based on their mental model of the aircraft's state and capabilities, while the other pilot may draw a different conclusion based on their own mental model. The interviews explored the extent to which causal and contributing factors to task management deficiencies and vulnerabilities may be related to differing expectations between pilots or between pilots and ATC.

3. METHODS

3.1. Participants

Sixty-one participants (Male=60, Female=1) were recruited from the domestic and international aviation industry. The majority of participants flew for U.S. airlines, with twenty-eight having experience of both domestic and international operations. Five participants flew for European airlines. Inclusion criteria included line pilots, check pilots, training personnel, and other personnel that have held some other, additional position in the industry which may provide them with insight or knowledge into task management deficiencies, vulnerabilities, and mitigations. For example, they may have held leadership positions in reference to training (e.g., director of training, supervisor of human factors training, training system designer). Participants were recruited through social media (e.g., LinkedIn), personal contacts, snowball sampling (i.e., recruited participants referred acquaintances), and participation in past studies. The study was reviewed and approved by the independent Institutional Review Board Arclight, Inc.

3.2. Semi-Structured Interview

Interviewing is a direct method for exploring a specific domain of expertise. As a natural process of inquiry, interviewing elicits information directly using everyday communication. This method can provide insight into the relevant tasks undertaken, the knowledge, skills, and procedures needed to perform these tasks, the learning processes involved, and associated pitfalls (Van de Wiel, 2017).

Semi-structured interviews were used in this work. Semi-structured interviews are for collecting qualitative data and follow a protocol devised prior to the interview; however, semi-structured interviews also allow for discovery with the space to follow topical trajectories as the conversation unfolds (Magaldi & Berler, 2020). The protocol consisted of pre-defined questions and researcher prompts to follow-up on interviewee responses (see Appendix B). Eight interviews were conducted in context (i.e., in the aircraft flight deck, in training simulator, etc.) as contextual interviews can deepen responses.

Pre-defined questions were based on insight from the literature review and focused on human factors of task management relating to civil transport category aircraft systems, flight deck operations, pilot procedures, and air carrier training and qualification programs. The items in the questionnaire were written in collaboration with a Honeywell flight test pilot and then refined using a think-aloud with subject matter expert (SME) pilots with Part 121/Part 135 experience to ensure clarity and intended purpose was adequately conveyed. The questions were iteratively revised through discussion with the FAA. To optimize time allotted for the interviews, questionnaire items were downsampled to decrease redundancy and ensure focus on important topics (i.e., largest gaps in the review and relevancy to research questions).

3.3. Transcription

During sixty-one interviews, fifty-four audio samples were recorded for transcription analysis. Due to technical issues, seven interviews were conducted without audio recording and subsequently relied on handwritten notes from the researchers. The audio from Microsoft Teams (version 24152.415.2975.367) was recorded in the MP4 file format. These were converted to .WAV file format. WhisperX (version 3.1.1) (Bian et al., 2023) was used for local-device audio transcription using Visual Studio (1.90.1) and Python 3.11. WhisperX is a Python-based implementation of Whisper, an AI-powered speech recognition model developed by OpenAI (OpenAI, 2022) with the addition of Pyannote (version 3.3.1) (Plaquet & Bredin, 2023; Bredin, 2023) for speaker diarization (e.g., automatic identification and separation by speaker). After conversion to .WAV file format, the audio was input to WhisperX, automatically transcribed with a timestamp, and then Pyannote automatically identified and separated the transcripts by speaker. The resulting transcript was output as a JSON file. The JSON file was then re-formatted and converted to text files for subsequent data extraction and analysis. Data security was ensured by using a local implementation on computers connected with a secure network.

Following automatic transcription, the transcripts contained errors. Whisper has shown high-accuracy in zero-shot performance, which refers to effectively transcribing datasets it was not specifically trained on (Zhuo et al., 2023). Whisper has also been shown to be robust in transcribing conversational speech in comparison to traditional models (Graham & Roll, 2024). However, it is not perfect, and the automatic speech transcription and diarization process resulted in errors that included substitutions, insertions, deletions, and incorrect speaker identification. Each transcript was manually reviewed by one of four researchers who listened to the audio and corrected the transcripts accordingly. A different researcher then reviewed each revised transcript to correct for errors a first reviewer may have missed. Grammar errors were corrected where the ASR made a mistake or to provide punctuation to improve readability. Natural speech such as filled pauses, disfluencies which are breaks or disruptions in the flow of speech, incomplete sentences, and incomplete words, were not modified[1], if that was how the participant spoke the words. Immediately identifiable information such as references to names, flight hours, airlines, and companies was removed along with indirectly identifiable information such as references to locations and contextually identifiable data. Interviewee responses were then organized under the highest-level questions interviewers posed to the participants. Participant IDs were removed. The final dataset consisting of 381,099 transcribed, anonymized words spoken by the interviewees was transferred to the FAA.

[1] Disfluencies and filled pauses were removed from quotes provided in this report to improve readability.

3.4. Data Extraction

The interview dataset was analyzed using a form of thematic analysis and coding for themes and subthemes associated with keywords. Coding involves labeling interviewee utterances to facilitate analysis. The three research questions posed in the Introduction and previous findings from the literature review were the starting point for developing the coding schemes shown in Table 1. Four researchers coded the transcripts in MAXQDA, and the coding process was iterative, involving multiple searches, passes, reviews, and discussion between the researchers. Excerpts that were determined through team discussion to be relevant were coded and extracted. Three researchers were human factors researchers with between 5 and 15 years of experience. One researcher was a pilot with 2500 flight hours and experience of two-person flight operations.

To actually perform the coding, the research team utilized the qualitative data analysis software Max Weber Qualitative Data Analysis (MAXQDA)[2] (version 22.6.1). First, all transcripts were automatically reviewed using the "autocode" search feature within MAXQDA. Extracted utterances were manually screened for correct context and then the retrieved text segments were coded. For example, any transcripts that had sentences containing "task prioritization" were automatically extracted using the "autocode" search feature and after reviewing the utterance for context and determining applicability, the entire utterance would be coded as pertinent to the theme *task prioritization* for later retrieval and analysis.

Auto-coding was part of the early coding process. Manual reviewing was a part of the next step. For example, an interviewee may have described comparing tasks (for prioritization), decision making (in a task prioritization context), or they may have described the concept or thought processes behind prioritizing. These utterances would not be captured by the auto-coding process, but during the manual review, the researcher would code those utterances as "task prioritization." The decision to code these as "task prioritization" would be based on criteria for the codes originating from the themes and sub-themes observed from the literature review and from review and discussion of the auto-coded utterances. For a list of codes used, see Appendix C – List of Extracted Codes.

After coding the transcripts, the labeled data was then more easily analyzed and accessible for comparison across multiple transcripts. Focusing on individual codes, retrieved segments were manually screened and considered for the contribution, novelty, and relevance in answering the research question. The prevalence of codes across the transcripts was also used to draw conclusions. Other analysis included reviewing the presence of several codes used in unison versus independently (e.g., if an interviewee utterance contained references to task prioritization and task shedding).

4. DEMOGRAPHIC SUMMARY

The following demographics describe the participant pool interviewed:

Total number of participants:	61
Gender breakdown:	60 male, 1 female
Average age of participants:	52 (std dev: 11.6)
Average number of flight hours:	14,562 (std dev: 9,953)
Most common number of ratings:	4

[2] https://www.maxqda.com/

Most common ratings: Boeing 737, Airbus A320 family, Boeing 757

Most common number of certifications: 5

Most common certification: ATP

Role or position at operator:
- Captains: 36
- First Officers: 19
- Check Pilots: 18
- Training Personnel/Other[3]: 13

Operational experience:
- Part 121: 55
- Part 135: 11
- Part 91k: 8

The participants were a broad representation of the population. The interviewees came from 16 different operators, and as shown in Table 1, the interviewees ranged in age from mid-20s to late 70s, and consisted of both Captains and First Officers.

Table 1. Ages by role for interviewees.

Age	Captain	First Officer	Training Personnel / Other	Total
20-30			1	**1**
31-40	1	8	3	**12**
41-50	8	7	2	**17**
51-60	11	2		**13**
61-70	14	1		**15**
71-80	1			**1**
Age not reported	1	1		**2**
Total	36	19	6	**61**

Twelve of the interviewees had prior military experience before becoming Part 121 pilots. The exact percentage of the current population of Part 121 pilots who have military experience does not appear to be known. However, one article estimated that currently, approximately one-third or 33% of airline pilots may have military backgrounds (Herstam, 2023). By comparison, 20% of the interviewees in this dataset had military backgrounds.

Figure 2 shows the breakdown of flight hours and the number of participants in each range. There were sixteen participants with more than 20,000 flight hours. On the other end of the spectrum, nineteen participants had less than 7,500 flight hours. The participants brought a wide range of experiences to the interviews.

[3] Individuals, who could be pilots, but who have held some other position in the industry, such as leadership positions in training departments (e.g., director of training, supervisor of training, training systems designer, etc.).

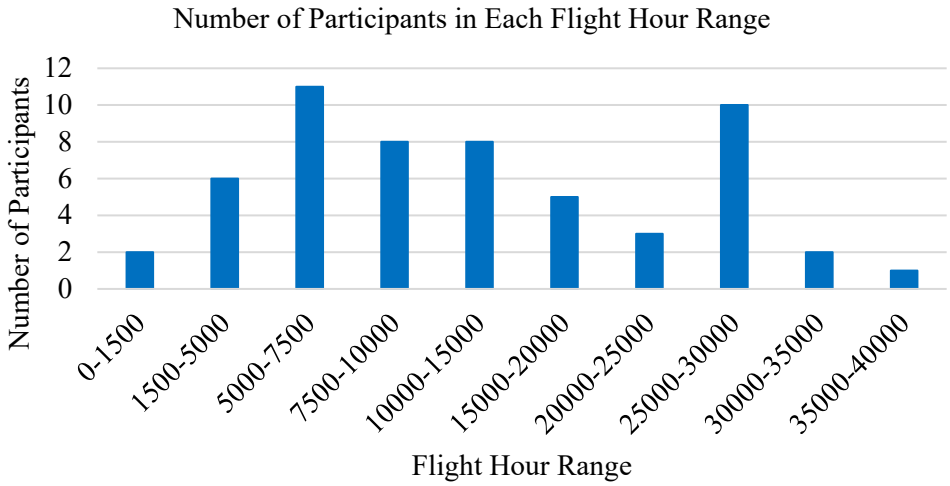

Figure 2. Number of participants in each flight hour range.

5. CAUSAL AND CONTRIBUTING HUMAN FACTORS

Causal and contributing factors to task management deficiencies and vulnerabilities were identified from the sixty-one participants. These factors were identified based on the described experiences and perceptions of the interviewed pilots. A summary of the factors as described by the interviewees is provided below. Sections 5.1 – 5.13 provide detailed breakdowns of the factors, along with example quotes from the interviews. Mitigations for these factors are described in the Section "Mitigations and Effectiveness."

The contributing and causal factors to task management deficiencies and vulnerabilities do not occur in isolation but are interconnected and related to one another. For example, complacency is a causal and contributing factor that may explain why a crew abbreviated their approach briefing and became engaged and distracted by social conversation. The social conversation is a distraction, another potential causal and contributing factor, which resulted in the crew missing an ATC instruction. The pilots then rush to complete tasks and mismanage their time, another causal and contributing factor, which results in dropping a task and deviating from the flightpath. Within this one example are multiple causal and contributing factors to task management deficiencies and vulnerabilities. Because of the overlap between factors, the relative importance remains unclear. It is also unclear how much each factor may cause and/or contribute to task management deficiencies and vulnerabilities. Further investigation is needed to determine that. For this reason, the order in which the factors are presented does not hold any significance.

Interruptions and **disruptions** are causal and contributing factors to task management deficiencies and vulnerabilities. Specifically, ATC interruptions during critical phases of flight (e.g., landing, emergencies) may overload pilots and/or result in task shedding. **Strategies for handling interruptions** differ; differences in strategies may be a causal or contributing factor to task management deficiencies and vulnerabilities. For example, some pilots indicate when they are managing ATC communications on landing, they will always wait until after the aircraft has slowed and they are ready to taxi. Other pilots indicate that the communication may interrupt a task, but they will respond.

Distractions are also a causal and contributing factor. Specifically, social conversation is a type of distraction that can affect task management. When social conversation is conducted at the wrong time, it can result in tasks being dropped or short cut (e.g., abbreviated departure briefing or approach briefing).

Complacency is another causal and contributing factor and social conversation can occur due to complacency. For example, when pilots are familiar with an arrival, they may feel complacent and engage in social conversation that can distract from tasks (e.g., approach briefing, communications), affecting task management. Complacency resulting from familiarity and confidence can also affect task management through short cutting of tasks which can affect FPM (e.g., inadequate briefing resulting in a speed bust on departure).

When conducted appropriately, social conversation can also be a mitigation to prevent a non-communicative environment (see Section "Communication to Mitigate Task Management Deficiencies and Vulnerabilities"). **Non-communicative environments** where crew members feel like they cannot speak up, cannot share ideas or concerns, and mutual understanding is limited are a factor contributing to task management deficiencies and vulnerabilities. Non-communicative environments enable poor planning, poor task allocation, hinder task execution, and increase potential for misunderstandings.

Effective communication supports building shared mental models for safe and effective task management. When communications are not timely, clear, concise, and understandable, shared mental models can breakdown leading to misunderstandings and slower task execution. In addition, communicating at the wrong time can hinder task management (e.g., continuing to brief during communications with ATC). Finally, being reactive in communication rather than proactive can contribute to improper task allocation and task execution.

Effective time management involves the ability to accurately perceive the passage of time and the amount of time needed to complete tasks. Time management involves both knowledge and skill that can be learned during training. However, pilots emphasized that operational experience hones the knowledge of how long it takes to complete tasks personally. **Incorrect perceptions of time**, both the time it takes to complete tasks and the time available to complete tasks, can result in task management deficiencies and vulnerabilities. For example, rushing because of an incorrect perception of the time available. A lack of **strategic time management** (e.g., reviewing weather ahead of time, getting the ATIS earlier in the flight when it is a short flight) is usually related to poor planning and can contribute to task management deficiencies and vulnerabilities.

Operational pressure and **social pressure** can contribute to incorrect perceptions of time and task management deficiencies and vulnerabilities. Pilots may have an artificial urgency to rush due to operational pressure, social pressure, or even behavioral tendency to act quickly. This may contribute to task management deficiencies and vulnerabilities; for example, shortcutting tasks like verifying an unclear clearance.

Taskload and **task saturation** can be causal and contributing factors to task management deficiencies and vulnerabilities. Taskload and task saturation are affected by weather and operational complexity. Weather can increase pilot taskload and lead to task saturation, and pilots may intentionally or unintentionally shed tasks as they struggle to keep up with the changing conditions. Conditions like mountainous terrain, operating at night, and new tasks from ATC introduced during demanding situations (e.g., preplanned flightpath is changed during certain phases of flight, runway change late in the arrival, vectored off a complex procedure and then vectored back on to resume published procedures) can also increase pilot taskload and task saturation, contributing to deficiencies and vulnerabilities.

Task allocation also affects taskload and task saturation and is a factor to task management deficiencies and vulnerabilities. Task allocation can be complicated, because the balance of tasks to avoid task saturation for one or both pilots is not always clear when operations become complex or when one pilot is less experienced. More experienced pilots may take on more tasks to support less experienced pilots; however, this may lead to task saturation for the more experienced pilot.

Fatigue and **stress** are also causal and contributing factors to task management deficiencies and vulnerabilities. Due to fatigue and stress, pilots may drop or shed tasks inadvertently (e.g., miss items on checklist, inadequately monitor flightpath and pass final approach fix). In addition, task saturation may vary due to fatigue, meaning the same pilot may become task saturated when they are fatigued sooner than when they are not fatigued. Many factors can contribute to fatigue, which can gradually build over time. Task management proficiency may correspondingly degrade as fatigue increases. Related to this, decision fatigue may also be a potential contributing factor to task management deficiencies and vulnerabilities.

Flight crew who have differences in **personality traits** (e.g., traits such as extroversion, conscientiousness, neuroticism, openness, agreeableness), **social behavior**, and/or **behavioral tendencies or work styles** may experience task management deficiencies and vulnerabilities. For example, different perspectives on when to accomplish tasks (e.g., approach preparation and briefing) can affect crew coordination and task management. Similarly, the ability to adapt and respond to unexpected events is different for different pilots and may be a potential causal and contributing factor to task management deficiencies and vulnerabilities.

In international operations, differences between **international ATC** and domestic ATC is a causal and contributing factor to task management deficiencies and vulnerabilities. Differences include phraseology, language, accent, and expectations regarding how pilots and ATC should interact. These differences can lead to uncertainty, decrease situation awareness, and increase taskload.

Finally, **system and operational complexity** are causal and contributing factors to task management deficiencies and vulnerabilities. The complexity of tasks related to programming and sequencing the FMS can result in loss of situation awareness, task shedding, and deviations from an intended or planned flightpath (e.g., not intercepting final). Operational complexity can increase pilot taskload, similarly leading to task shedding and deviations from an intended or planned flightpath.

5.1. Interruptions, Disruptions, and Distractions

Handling interruptions, disruptions, and distractions is a component of effective task management. Interruptions can be pauses in a task, activity, or workflow due to ATC communications, environmental conditions, malfunctions, failures, crew communications, or other factors. If a task is interrupted before its completion, the original task could be abandoned (e.g., task shedding), with the interruption becoming a transition to a different task, or it could be resumed after the interruption is resolved. Operational situations that prevent a pilot from successfully completing a task can also be described as disruptions. Distractions are characterized by a shift in attention away from a task to another stimulus. There are nuanced differences between interruptions, disruptions, and distractions; however, in reviewing pilot interviews, the researchers did not attempt to differentiate interruptions, disruptions, and distractions but grouped the terms together, as pilots used these terms interchangeably.

The most common external factors interrupting pre-flight tasks are communications from ground personnel, cabin crew, and passengers. Interviewees described struggling to find methods to manage these interruptions. The interruptions can often provide information the pilots need but distract from and disrupt tasks the pilot is performing, leading to task management errors if not handled correctly. One interviewee, as quoted below, leveraged the cabin crew to help manage distractions.

> "*There's all kinds of distractions… The flight attendant comes up and says, 'hey, we need catering.' 'Can you call catering?' And sure, you know, so we're in the middle of a task and that happens and then maybe a passenger will stop: 'Oh, can I say hello to the captain?' Little kids that just love to come in and have their picture taken on the flight deck. All of these things happening during boarding. But at the same time the flight deck is going through some setup procedures and so it's very easy for communication and task management to get disrupted by all of these distractions and things going on… We don't like to close the door, that looks a little bit unwelcoming or like you're trying to cover something up, so we just have to tell the flight attendants out front, 'hey… just… we're kind of in the middle of something here. Can you just kind of not let any distractions come through for four or five more minutes?' And they're usually very good about that.*"

Quote 1. Communications that interrupt tasks may provide useful information. but the interruption may result in distraction and disruption of tasks.

Across all other phases of flight, the most common factor interviewees described as interrupting their tasks was ATC communications. ATC can interrupt tasks during any phase of flight and these interruptions can affect pilot task management in several ways. Primarily, ATC can interrupt a pilot's current tasks to introduce new and unanticipated tasks. The new task or tasks from ATC may mean pilots need to re-prioritize and re-allocate resources to manage the new tasks. Pilots may experience increased task load and workload and may inappropriately shed tasks. The extent to which the new task or tasks affect workload and initiate re-prioritization efforts depends on the complexity of the new task and what the pilot is currently doing. Interruptions during the arrival and approach such as ATC vectoring an aircraft off an arrival or introducing a late runway change are times where pilots are potentially more susceptible to task management errors as a result of the interruptions. Several pilots commented that the effects on task management and task load can be exacerbated, particularly during the arrival, if ATC changes their instructions multiple times (for example, as the two interviewees describe below, changing approaches several times due to weather). This can lead to task management errors on the part of the pilot as they attempt to manage the changing task environment.

> "*During the summertime, when you get all those little pop-up thunderstorms, you'll get cleared to do one arrival, and then they'll say, 'hey, we're going to reroute you over to this one.' So, you start to get all set up for that and start heading down that arrival. And a few minutes later, 'oh, we need to go back to what you were doing.' That's frustrating as all get out. Number two, it's created a whole lot more work and by proxy- a whole lot more room, a lot more opportunities for mistakes to be made.*"

Quote 2. Multiple control instructions or ATC interventions can increase pilot workload and increase risk of task mistakes.

> *"Denver in particular is just one of these places where it's like the lottery and you just don't know what you're going to get. They'll change it on you last minute. And I've had it before where… they changed [our runway] three times. Sometimes I don't think they realize the amount of work that it takes for us to go in and change a runway and change fixes while staying on course and everything else… it adds a ton of work for us, especially the pilot monitoring."*

Quote 3. Interruptions during the arrival and approach can introduce new and unanticipated tasks.

Thirty-five pilots discussed ATC communications interrupting their tasks during critical phases of flight, such as landing, or during emergencies. When an aircraft declares an emergency, ATC has tasks they need to complete, and their requests for information can interrupt tasks. While pilots know they can say standby or wait to respond and several interviewees attested to waiting to respond to ATC during landing, ATC communications can still interrupt task flows, distracting from the tasks pilots are executing. In addition, knowing that one can ask for more time and actually asking for more time do not go hand in hand. The below comment from one pilot describes why receiving ATC instructions during landing can be problematic.

"The biggest problem … I see on a day in, day out basis is tower giving us instructions while we're slowing the aircraft down on landing. Because there's a lot of things going on task-wise, not only pilot flying the airplane, slowing the airplane down, but the pilot monitoring making call-offs and monitoring the proper deceleration of the airplane. And of course, the higher noise factor from the reverse thrust in the engines is when ATC will come on and give us instructions … the instructions themselves are not the problem. It's the instructions at a bad time."

Quote 4. ATC communications can interrupt task flows, distracting pilots from tasks.

Another interviewee's comments regarding responding to ATC on landing indicates that how pilots manage communications that interrupt other tasks during a critical phase of flight, such as landing, can vary. This pilot was discussing how ATC can call while they are managing the landing. They commented that sometimes they respond, sometimes they wait to respond until they are taxiing, and sometimes they "just do it," meaning they respond to the ATC even though it is not ideal to do so from a task management perspective. This suggests potential for task management deficiencies and vulnerabilities as pilots may be disrupting their tasks on landing to respond to ATC when they really should wait to respond. There may be component of operational and/or social pressure to respond to ATC immediately that is also playing a role in how pilots are managing communications to ATC during critical phases of flight, such as landing.

"Sometimes you may have plenty of time in the landing roll to actually answer him and acknowledge. And sometimes you just do it. And sometimes you just ignore him and say, okay, we'll get back to him when I'm done."

Quote 5. Pilots may inconsistently prioritize responses to ATC.

Finally, some interviewees discussed that conversation can be distracting. One interviewee commented that they missed radio calls when a crew member did not respect the "sterile cockpit" rule and wanted to converse below 10,000ft. Another interviewee discussed a scenario where they were flying with an inexperienced first officer and an experienced check pilot into weather. Conversation resulted in the interviewee feeling compressed for time and distracted by the conversation during a time where they needed to focus on tasks.

"So, I start looking and I'm like, wow, there's a lot of weather down there right now. Where did that come from? All of a sudden when it felt like we had a lot of time to take care of certain things, we were very, very time compressed. We're low on fuel… and I've got a pretty new first officer with a very experienced check airman, and he's [the check airman] awesome, but it can also be a distraction, because he wants to still be talking about [vacation] things and lessons learned and things like that. And it's kind of like, okay, let's put that aside right now. We got to start getting ahead of this. Cause now I'm feeling time compressing behind."

Quote 6. Non-pertinent conversation between pilots can lead to distraction and loss of awareness.

5.2. Complacency

Pilots may become complacent when they become overly familiar and confident with their performance of routine tasks. As a result, they may underestimate potential risks. Pilots may also become complacent towards the cross-verification process due to the high degree of reliability and integrity of systems (PARC/CAST, 2013). Complacency can lead pilots to short cutting or dropping tasks. The interviewees described different circumstances where they became complacent and either short cut or dropped tasks.

One interviewee described a situation where they busted a speed constraint on a departure. The interviewee attributed the bust to complacency, stating that they did not thoroughly brief the departure procedure, because of complacency. They did not brief it adequately because it was the first flight of the morning (e.g., they felt good, environment and operating conditions were good, they felt confident), and they were overly familiar with the routine.

> "*Taking off we missed a speed limit on the departure … We got up above 10,000 feet and we're accelerating through 300 knots and ATC, asked us how fast we were going. It's kind of like, "oops!" It was just complacency… It was the first flight of the day… We didn't thoroughly brief the departure procedure, didn't adequately brief the departure procedure. Neither of us caught that… you get complacent. Just kind of go through your routine."*

Quote 7. Complacency resulting from familiarity and confidence can affect task management through short cutting of tasks which can effect FPM (e.g., inadequate briefing lead to a speed deviation on departure).

Similarly, another interviewee spoke about a situation where they were flying into an airport both pilots were familiar with. The approach was a visual approach on a cloudy day with low weather and low visibility. The interviewee stated that they did not brief the approach as much as they should have; both pilots were relying on their experience. While this experience and familiarity meant that they were able to manage the approach, upon landing, they both acknowledged that they should have briefed the approach more, and that due to their complacency, they inadvertently increased their task load on the approach.

> "[*We were] very, very familiar with where we're going and so we didn't plan ahead as well. We're relying on our experience rather than really looking at the situation. We ended up down low on a visual approach going in on a partly cloudy day and the visibility wasn't as good as we expected… It worked out okay. We got to the runway, we both had so much familiarity that that did compensate, but we got on the ground and went, well, we should have talked about a lot more of that a lot sooner."*

Quote 8. Relying on experience and confidence, pilots may shortcut tasks (e.g., approach briefing), impacting planning, strategic task management, and contributing to higher task load and less effective tactical task management.

In the Section "Interruptions, Disruptions, and Distractions," interviewees described how conversation can be a distraction which can impact time management as well (see Section "Perception of Time and Time Management"). Conversation can also occur as a result of complacency, when pilots feel comfortable and familiar with an arrival. As described in previous sections, conversation as a result of complacency can be a distraction contributing to time and task management deficiencies. In the example below, the interviewee describes an arrival both they and their fellow crew member were very familiar with. They allowed themselves to get distracted by conversation, partially due to that familiarity, and missed a radio call from ATC. The result was an increase in task loading, as they made up for missed ATC instructions.

> "*When we're doing something, we've done a million times [like] on this particular arrival, we were landing to the northwest. They bring you on a downwind and turn your final. We're about 2,000 feet and the guy I was flying with … and we're just sitting there talking, you know, it's like 'OK, hey, yeah, we can expect this, yada, yada, yada. OK'. And then… we're like 'Oh, hey, you know, what's going on here?' Like, 'Oh, yeah, well, that building over there is this and… well, that's cool'. [talking about new construction]. Then all of a sudden you hear the dreaded phrase '[aircraft call sign], where are you going?' We were like 'Did we miss a radio call?' [Then ATC replied,] 'Yeah, you missed about two. So, turn to this heading' … now we've added a bunch of more tasks because now ATC is giving us directions we're not anticipating and we're like deer in the headlights."*

Quote 9. When pilots are familiar with an arrival, they may feel complacent and engage in social conversation that can distract from communication tasks.

5.3. Barriers to Crew Communication

At the highest level, communication can be considered as the transmission of messages and the production and exchange of meaning (Shannon and Weaver, 1949; Ayer, 1995; Fiske, 1990). Communication is frequently described as a "dance" because like a dance, effective communication involves a rhythm, coordination, and a mutual understanding between speakers. Communication on the flight deck is dynamic, reciprocal, and fluid. It is affected by barriers such as rank, age, gender, and organizational culture and by individual factors such as speaking skills, listening skills, decision-making skills, conflict resolution techniques, assertiveness, and advocacy (see Literature Review). The interviews highlighted how barriers and factors affecting communication subsequently impact task management. This included how clear,

concise, and unambiguous communication can support coordinated decision-making and execution of flight tasks, and how in high-stress or emergency situations, unclear, ambiguous communication may contribute to task management deficiencies and vulnerabilities.

A communicative environment where all crew members feel they can express their thoughts, ideas, and concerns can lead to better collaboration, understanding, and problem-solving. In the opposite of a communicative environment, crew members feel like they cannot speak up, cannot share ideas or concerns, and mutual understanding is limited. Communication involves both speakers; if one speaker does not engage or support a reciprocal and fluid exchange, this can result in a non-communicative environment. On the flight deck, the communicative environment impacts task management. For example, in the below quote, the interviewee describes an experience where they were acting as a first officer and the captain's behavior contributed to a non-communicative environment. The interviewee felt they could not speak-up. As a result, the interviewee describes becoming passive, non-interactive, and this hindered their ability to manage and execute tasks, including ensuring safe operations of the flight. This type of non-communicative environment can also lead to a breakdown of the crew's shared mental model, as one of the pilots is no longer actively communicating, engaging, and contributing. The breakdown of the crew's shared mental model can affect task management through increased misunderstandings and slower task execution.

> "*And so, this check airman created an environment that was hostile. It was to the point where you couldn't speak up. It was 'you're wrong. I'm right. I know everything. You're dumb' … now there's a thunderstorm over top of Montego Bay, solidly red… [Other aircraft] are holding, waiting it out. He gets the bright idea. No, we were going in, it's his leg. And I'm like, this doesn't look right. It doesn't sound right, but we're pushing it on. The plane is bouncing all over. And I'm thinking to myself, this is the dumbest thing I've ever done … because he had driven into me that it was, 'I'm smart, you're dumb' it created an environment where I was unwilling to speak up and say, 'Hold on a minute, maybe we should hold for 30 minutes' ... You need to create an environment in a two-person cockpit that you want interaction from the other person ... you become passive, and you become almost passenger-like when the reality is you need to be an active participant."*

Quote 10. Non-communicative environments can lead to breakdowns in the crew's shared mental model of the flight and the execution of tasks that includes ensuring safe operations.

Because communication involves all the individuals participating, one individual can easily make or break the exchange, as shown in the above example. Several interviewees provided similar examples in different contexts. One interviewee described a scenario where, as a check pilot, they were observing a crew who were dealing with a maintenance issue on the aircraft. During their preflight briefing, the FO attempted to bring up the maintenance issue, but the captain did not engage in any discussion. The interviewee who was observing reflected that this led to a lack of planning on the crew's part. When the crew encountered the issue on departure, they were not ready for how to respond to the issue, because they had not discussed it. The aircraft momentarily entered an undesirable state. The interviewee noted that there were several communication breakdowns between the captain and FO; an important contributing factor was the "tone" of voice and the environment that the captain fostered. This factor had downstream effects on the crew's shared mental model and their ability to manage their tasks in the moment.

"*The airplane is doing something that it doesn't normally do… The crew knows, and they're briefed on the fact that this is an issue. And yet they fail to address it really in their planning process. And sure enough, on departure, what had been happening happens again. And it resulted in an undesirable aircraft state momentarily while they figured out what was going on. That was one of those situations that, had they actually talked about it, what is the mitigation plan, because there's a strong likelihood that this is going to happen again, what are we going to do [then it would have helped]. [But] the captain had shut the FO down when the FO had started asking some questions… The captain's like, "Hey, that's already taken care of." And it snowballed from there… Tone and tenor are very important… If you walk into the cockpit and shut that down, that can be incredibly detrimental to what happens with the rest of the flight."*

Quote 11. Communication breakdowns can lead to poor planning impacting strategic and tactical management of tasks.

Communicating effectively is a skill. Knowing what to communicate, when to communicate, and how to communicate on the flight deck is learned. Several interviewees talked about their experiences of both learning what and how to communicate with another pilot as well as working with pilots who may not have developed that skill yet, and how that impacts task management. For more experienced pilots, being able to recognize that a less experienced pilot may still be learning what, when, and how to communicate is itself a skill, and exercising that skill is important to supporting task management as a crew. In the quote below, one of the interviewees talks about how they did not know how to communicate and work with another pilot at their first airline job. They were hesitant about what to do and would just wait for the captain to tell them what to do. Another pilot recognized the interviewee needed guidance in how to communicate and accomplish the tasks they needed to do, and this completely changed how they went about communicating and completing tasks.

"*I went into my very first airline job … I would sit there and wait for the captain to tell me what to do…and [I] almost got fired from that job. I just had no training at all in how to work with another pilot, how they kind of coordinate two guys working together. And I was really fortunate, I had a chief pilot that sat me down and figured out that that's what the problem was. [He] gave me half a dozen little tasks, like here when you get in the cockpit, do this this this and this and join the crew and … overnight it completely changed personalities."*

Quote 12. Communicating effectively involves being proactive; some pilots may need additional guidance and training in how to be proactive and manage tasks as a crew.

"It was in a [airline] environment where I had a captain use non-standard language, non-standard flow, non-standard checklists and using hand signals that were not standard or not briefed to me, and then him… he said 'hey, why aren't you doing this?' I'm like, 'well, I don't understand what you're asking'. So, it's ineffective communication. We didn't have a shared site picture or shared understanding of what we needed to do. No common picture"

Quote 13. Differing communication styles can lead to a mismatch in mental models and expectations.

Another interviewee discussed how not being aware of the communicative environment and communicating when other dialogue is occurring can negatively impact task management. They described an experience where there were multiple crew members talking over the radio. The pilot who gave the approach briefing did not stop the briefing when other conversation was occurring, including when ATC called. This resulted in the crew missing an ATC instruction, and the interviewee felt they were less prepared as a crew for the approach.

"*So, this particular flight, it was just, you know, the entire flight that the crew was talking over the radio. That impacted everything in the cockpit. Now the guy in the left seat just gave a brief that nobody was really listening to because he didn't stop his brief while ATC was talking. So now we missed a radio call and… now we just concluded our briefing but meanwhile you know nobody even heard the briefing."*

Quote 14. Communication tasks can be missed, dropped, or performed inefficiently depending on the operational environment (e.g., if there is conversation/dialogue over the radios).

The below example contains several factors that contributed to task management deficiencies and vulnerabilities; however, one factor the interviewee highlighted was their communication. In this example, the interviewee was the FO and pilot flying. The crew received a request from ATC to go direct to a fix. The captain exhibited a knowledge gap in programming the FMS. In responding to the captain, the interviewee attempted to do the task themselves, but they did not effectively communicate this to the captain. As a result, they generated more confusion, and the task took several times longer than it would have otherwise.

"*This is probably the simplest task you could possibly ask somebody to do. And between the two of us, it took quite a while. So, air traffic control told us to go direct to a specific fix. And I was the pilot flying. He was the pilot monitoring. So, he was the one that was supposed to be in charge of manipulating the FMS into taking us direct. But when we initially got the instructions, he began fumbling around in the FMS… he was confused about exactly what it was he needed to do to get the FMS to take us to direct. And instead of just telling him what to do, my first instinct was just to do it because I thought that it would be easier and faster. But in doing that, we ended up working against each other to put the direct fix into the FMS. So ultimately, the whole thing took us probably in the neighborhood of 20 or 30 seconds for something that was maybe less than five seconds worth of work. There was multiple breakdowns in there. One is that, you know, he didn't fully understand what he was trying to do with the FMS or how to do it. And two is rather than effectively trying to communicate to him how to do it so that our tasks remain the same as they're originally assigned, I opted to just try and do it, which even further confused him. So, I think just all in all that was a pretty poor example of managing the very, very simple task.*"

Quote 15. Task execution can be hindered when communication of task allocation is unclear.

Finally, communication can be task-based, or it can also be social, for the purpose of building rapport and learning how the other individual thinks. Fifteen interviewees talked about how social communication can help maintain alertness during periods of low workload and contribute to a crew's shared mental model. When pilots do not engage in social conversation, rapport and joint understanding may be lower, which could contribute to the breakdown of the crew's shared mental model. The two quotes below from two different interviewees highlight this potential task management deficiency and vulnerability. The first quote is from an interviewee, a captain, describing how social conversation can contribute to their ability to manage tasks together with their FO. The second quote describes how the lack of social conversation can be a barrier to task management by limiting rapport building and joint understanding. However, some individuals may possess a more quiet and reserved communication style. Differences in communication style and personality and effects on task management are discussed in the Section "Individual Differences."

"This is why it's nice after flying with someone for a few days, because you get that conversation… you get to learn. Where did you learn to fly? What did you do before this? … You start building those…mental models of what other pilots are like and what they do…. so maybe at the end of the day, you're still not seeing eye to eye, but you're able to predict what that person's going to do in that situation."

Quote 16. Social conversation can help build shared mental models for task management, aiding joint understanding and supporting task execution.

"Let's just say you've got somebody in the cockpit that just isn't a talker. They … just kind of go off in their own little world or they just look out the window… if a situation does pop up, whether it's an emergency or even something that's not an emergency, but we've got to run through various checklists… if you're not real comfortable communicating with the guy, it can definitely present a barrier."

Quote 17. Lack of social conversation can hinder building of shared mental models for task management, creating barriers to joint understanding and task execution.

5.4. Perception of Time and Time Management

Time perception is how one perceives the duration of events, and time management is effectively managing the time available to initiate and complete tasks (PARC/CAST, 2013). To manage time, an individual needs to be able to think ahead and be able to accurately perceive time. An individual must (a) know the time it takes to perform an action or task, (b) know the correct time to act on a task, (c) be able to update their awareness of the current time and knowledge of how much time is left to do or complete a task, and (d) determine and update the priority of a task (i.e., how long will the task continue to be important, how is the importance of the task changing over time) (Rantanen, 2009).

The interviews suggested that it is through both training and experience that pilots develop knowledge and skill in how they perceive time and how they manage their time strategically to accomplish tasks. Some pilots learned strategic time management practices through experiencing the consequences of improper time management in specific contexts. For example, in the below quote from a check pilot interviewee, they describe an approach to an airport in mountainous terrain that is rarely used except in certain circumstances, such as at night. The flight deck crew were encouraged to strategically manage their time by briefing that approach as a backup plan, particularly given potential operational complexity; the interviewee observed that flight crew who did not brief the approach as a backup plan made mistakes. These mistakes could be compounded by conditions such as flying at night and terrain.

> *"It's just a little bit more challenging than the normal approach. But in multiple cases, we've had crews who were alerted that they should brief that as a backup plan just in case their [runway] changed at the last second. And, you know, multiple crews have not done that. And then a very late approach assigns them those [south] runways. So, they have to figure out where to go and how to shoot the approach and how to reprogram the flight management system to fly that approach all in a very short time at a very low altitude above the mountains at night. And it gets screwed up all the time."*

Quote 18. Backup plans can prevent task management deficiencies that may be compounded by operational complexity.

Similarly, another interviewee discussed that managing time strategically was a lesson they learned the hard way when they and their fellow crewmember became rushed and had to repeat tasks (e.g., getting ATIS and briefing the approach) several times on a short flight. As a consequence of getting behind and overloaded on that short flight, the interviewee discussed learning both time management techniques (e.g., using time effectively) and task management techniques (e.g., task initiation and prioritization) for when to get the ATIS and using their time wisely in terms of how they assess the ATIS for potential changes.

> *"It was really short [flight]… so, by the time you get up… by the time you're at the altitude you picked, you're already getting vectored onto the approach. So, it's like the minute you leave, you're already getting the weather. You're already briefing the approach… that's a time where the two of us let the pace of the flight get a little bit ahead of where we were, just because of how quick everything happens… We had to listen to the weather like probably three or four different times to be able to capture it. In briefing the approach plate, we had to stop and restart it two or three times… With the weather for a flight that's as short as that, [now] we get the weather before we leave and when we get up in the air and you hear information Kilo is still current… then it's still the same as what it was when you took off."*

Quote 19. Getting behind the aircraft can affect task management by leading to overload and repetition of tasks.

Another factor that is related to the two previous examples is that pilots must be aware of how much time they need personally to perform tasks, especially given any other tasks they may need to perform. This knowledge can help pilots manage their time strategically, and it is developed both during training and through experience, as with the above example collecting the ATIS in the context of a short flight. Several interviewees who had more than 15,000 hours of operational experience discussed how they monitor and are aware of the amount of time their fellow crew member(s) need to perform their tasks. These interviewees described that they use this additional knowledge to modify their own time and task management strategy,

as in the below quote from one of these interviewees. They describe being able to quickly assess the amount of time their first officer needs to accomplish tasks. This interviewee then adjusts their own strategy depending on the needs and abilities of their first officer.

> *"You can tell pretty quickly the speed at which your first officer is going to be able to accomplish tasks. Some of them can do them really quick… There's others that cannot do that… So, you need to recognize the person that you're with and adjust to that person. You can't just be rigid all the time. In one direction, one way. You have to be able to change your workflow based off the people that you're with that particular flight."*

Quote 20. Experienced pilots recognize and adapt time management strategies to other pilots.

The interviews also suggested that incorrect perceptions of time can lead to task management deficiencies and vulnerabilities. In the quote below from one interviewee, they describe a situation in which they assumed a clearance to takeoff was for them. This quote presents several factors of task management deficiencies and vulnerabilities that will be touched on in other sections (see section on "Barriers to Crew Communication" and section on "Effects of Operational and Social Pressure"); however, one contributing factor was an incorrect perception of time. The interviewee states that they felt they were late, and they were "rushing" so they did not take the time to perform tasks properly to verify that they were actually cleared to takeoff. This incorrect perception of time, meaning they perceived that they had less time than they may have had, resulted in task management deficiencies.

> *"What happened was we taxied out to the runway ... We had another flight with a similar call sign getting ready to depart [on a different] runway. And we had company on about a three-mile final runway [on] our runway ... But what I heard was our call sign… And I wasn't sure. I wasn't 100% sure. I was probably 70% sure that was for us. I asked my FO. I said, was that for us? Really a poor way to ask that…. I said, was that for us? And he goes, yes. And I said, okay, let's go. Came around the corner, pushed the power up. We had plenty of spacing with the aircraft on final. Pushed the power up, initiated the takeoff, and that clearance wasn't for us. It was for company on [the other runway], and he was rolling also. And they had him abort the takeoff instead of us. He aborted the takeoff, stopped well before the intersection of the two runways. We rotated before the intersection of the runways as well... What I decided from that was don't assume anything. I never ever did that again where I asked the FO, 'was that for us?' If I had any doubt at all for takeoff or landing or any other clearance, I would ask the FO, get verification that that was for us. Verify that was for us for that landings or verify we're clear to land. Verify that takeoff clearance was for us. Use ATC as a tiebreaker … It scared the crap out of me that I could make a mistake like that … [from a task management standpoint] I was rushing. I was rushing. I was late… I assumed it was similar call signs. I didn't appropriately use my resources. ATC is a resource. I should have asked the FO to ask ATC if that was for us. I didn't manage tasks appropriately on that flight."*

Quote 21. Time pressure or pilot perception of time pressure can lead to breakdowns in tasks.

Incorrect perceptions of time may contribute to task management deficiencies and vulnerabilities in other contexts as well. In the below example, the interviewee describes a situation in which the pilot flying delayed making a decision regarding their flightpath and potential turbulence. This delay may have been due to several factors. One factor may have been an incorrect perception of the time it would take to encounter the turbulence and the time they needed to adjust their flightpath.

> *"There was moderate turbulence. I looked at the first officer [pilot flying] and I recommended possibly climbing to a different altitude. He was hesitant… And then we continued hearing other aircraft requesting different altitudes. ... [I said] 'we really need to think about doing something different than what we're doing here.' And at that point … I think he was kind of convinced it was time to do something different. We weren't quite in the chop yet, but by the time he made a decision on what to do as pilot flying, we had gotten ourselves into moderate chop."*

Quote 22. Incorrect perceptions of time may result in delayed pilot decisions.

In order to perceive time, pilots must be aware of time and observe the passage of time. A lack of awareness of time can lead to poor time management, which can then lead to task management deficiencies and vulnerabilities. Pilots may become unaware of time passing for several reasons, including interruptions and distractions. In the below examples, interviewees provide two cases in which pilots can become distracted and not perceive the passage of time.

> *"Sometimes, when you first deal with the crew, people talk, start talking and stuff, and sometimes you have to remind them that 'hey, you know you're like 15 minutes from departure?' and so I have to throw out a hint like, isn't the clearance up yet? Or something like that, just to … trigger them to think 'oh, wait a minute I got a lot of stuff to do."*

Quote 23. Pilots may become unaware of time passage due to distractions.

> *"You might get involved in a conversation or whatever and not realize the time crunch that you're putting yourself into, i.e., you're getting a lot closer to the airport when things really start getting busy with clearances and air traffic control. [Then] you're having an issue in performing just normal tasks that you normally would have done miles back when you didn't have a time crunch. I think time management is probably the most essential part of trying to stay out of a situation where you're [in] jeopardy"*

Quote 24. Pilots may become unaware of time passage, which may lead to increased time pressure for normal tasks.

5.5. Effects of Operational and Social Pressure

Pilots can be the recipients of operational and social pressure exerted by other pilots, dispatch, flight attendants, passengers, the airline company, ATC, ground personnel, and other sources. Through the form of expectations, norms, or direct persuasion, social pressure can influence pilots' thoughts, feelings, and behaviors, and this influence can affect pilot task management. In the interviews, pilots described the impact of several different social pressure factors on their ability to manage tasks, with cultural expectations being a common factor pilots described as contributing to task management deficiencies and vulnerabilities. Cultural expectations are the norms, values, and behaviors a particular organization or society emphasize. Pilots can experience cultural expectations from their societal culture, operator culture, and the culture of any other groups or societies they may belong to. An operator's cultural expectations are shared through company mission and vision statements, defining core values, the work environment, policies, metrics, training, leadership, and more.

Cultural expectations may shape how pilots perceive and prioritize their responsibilities and therefore tasks. Several interviewees discussed experiencing social pressure to accelerate their tasks from their fellow crew members, from ground personnel, from the cabin crew, from gate personnel, and from passengers. Several pilots described applying pressure to themselves to rush, potentially as response to the external pressures they sense or feel from others. The experience of this pressure was typically described in general statements, as shown in the quotes below. In the first quote, one of the interviewees described how operational pressure to ensure the first flight of the day gets out on time can lead to pilots rushing to complete tasks, with the implication that this can lead to task management deficiencies. In the following quotes, the interviewed pilots describe how other people invested in ensuring the aircraft leaves the gate on time may pressure pilots to complete tasks quickly.

> *"They have a very strong metric that the first flight of the day gets out on time and overwhelmingly they'll have three or four supervisors hounding on the operations agent to get that flight out of here. Now, as a captain, it's up to me, but they give you negative pressure to do that… They put too much pressure on it to the point where people get hurried and then things start missing [as] they get rushed."*

Quote 25. Operational pressure can lead to pilots rushing and the potential breakdown of tasks.

> "*There's so many people in the chain… we have gate agents, we have mechanics, we have the people that actually push the airplane, the ground crew. And all of those people are incentivized to get the airplane out on time… so, when they see that the time is clicking down and they are ready to go… they start applying pressure [to the pilots].*"

Quote 26. Operational pressure can lead to social pressure and potentially affect task management.

Interviewees provided examples of how the pressure to rush, particularly at the gate and when preparing to takeoff, can have consequences for task management. In Quote 21 in the previous section on "Perception of Time and Time Management", the interviewee described being rushed and as a result, they did not take the time to perform tasks properly to verify that they were actually cleared to takeoff. Similarly, in Quote 27 below, the interviewee described a scenario they had witnessed where the crew forgot to set flaps, because they had been rushed to not miss a slot. The flight crew discovered the incorrect flaps setting when performing the takeoff config test.

> "*There was a crew that they were really, really, really pressured, because they had to make a slot, and they forgot to put the flaps out. And when they did the takeoff config test… then they realized that their flaps were not set. And that's why, because… they had pressure of losing a slot*"

Quote 27. Operational pressure can lead to time pressure, which may result in not adequately preparing for takeoff.

Social pressure can also arise when pilots must make a FPM decision, such as diverting when there is weather at the destination airport or when there is a medical emergency on board. In these instances, they may face social pressure to make a particular decision. In the example below, the interviewee was the captain on a flight into Denver. Due to weather, only CAT III approaches were being allowed, and the aircraft and crew could only perform CAT II approaches. The crew were holding, but they were approaching the minimum fuel where they could still make it to their alternate, Albuquerque. The closer airport of Colorado Springs was saturated, and the interviewee made the call to divert to Albuquerque. At that time, dispatch pressured them to stay and attempt to land, as CAT II approaches were being allowed intermittently. However, the interviewee decided they did not have fuel to try the approach and still make it comfortably to Albuquerque if they needed to go-around. They diverted, but they recalled the feeling of being pressured to continue and debating whether they were making the right decision.

> "*The weather in Denver was 6, 6, and 6. It was CAT III approaches. And even then, I think there was a few go-arounds. They wouldn't even let a CAT II approach attempt. We saw the weather as we were approaching so we're already trying to get more information from dispatch. Our alternate is Albuquerque. We're explaining to them… Albuquerque is a little further away from Denver than Colorado Springs and it limits the amount of time we can hold and wait for the weather to get better … We started looking at the fuel …We gave dispatch one more chance to change the alternate if they wanted us to hold a little longer. At that point, Colorado Springs was clobbered. We said we'll stick with Albuquerque. We were approaching that fuel that we need to leave, and we were already starting to execute our divert plan …. Of course, the passengers are never happy about having to go somewhere else, but it was the right and safest thing to do. Right about when we were leaving, they were starting to take CAT IIs into Denver. Dispatch was trying to talk us into giving it a shot. As the captain, I pretty much had to say, no, we missed that opportunity. We're going to Albuquerque. Because that would have put us pretty, pretty restricted on fuel… there's a high probability we wouldn't have made it in there.*"

Quote 28. Dispatch may pressure pilots to make different task management decisions.

While the interviewee in the previous example felt they had made the right decision, another interviewee described a situation in which they had to decide whether to divert in response to a medical emergency or continue to their destination. As an additional complication, the closer they approached to their destination, the more weather increased and their options to divert decreased. As the captain, they knew they had the authority to divert and in retrospect, they wished they had diverted immediately. However, in the moment, they felt social pressure to continue to their destination.

"*There were occasions where I wish I had done something else. Like for example, a medical emergency… it was a summertime flight. There were thunderstorms all up and down the northeast coast. And we had somebody who had stroke-like symptoms in the back. I'm getting a phone patch to my dispatcher and our medical advisors… and they're telling me to continue and I'm saying… 'this individual has stroke-like symptoms. Maybe we need to get them on the ground'. They said, 'Give us an update in 20 minutes.' I knew the further we went north, the less opportunity we would have to divert quickly to another field… I just wish I'd made a different decision and just said, hey, this is Captain's authority. I'm diverting… It was tough.*"

Quote 29. Social pressure can affect decisions about flightpath diversions.

Pilots are called to make many decisions throughout their duties, and it is not always apparent what the best course of action is. Some of these decisions balance different pressures, as in the example below, where the interviewee describes deciding whether they delay for catering or prioritize being on-time. These decisions are additional tasks pilots need to manage and perform, and for this interviewee, these decisions can be fatiguing. Decision fatigue can be a potential contributing factor to task management deficiencies and vulnerabilities.

"*In the real life, in the real world, you've got all these things that pop up and it's, and you know, you have to constantly be prioritizing the importance of whatever those things are, whether it's the flight attendant just telling you that catering just called and they don't have certain meals or they don't have water and they they're looking for it, and so we have to make a determination, you know, how long we're going to delay, for example, because you know, obviously on-time departures and on-time arrivals are a priority for the airline and so you have to make these decisions, and there's just a million of them, in a, in a, in a million, I mean, maybe in a four day trip or something, you just constantly, it's just constantly bombarded with all these different unexpected little challenges.*"

Quote 30. Pilots make frequent decisions that balance different pressures, like prioritizing receiving catering versus departing the gate on-time, and these decisions can be fatiguing, which can impact task management.

In some situations, social pressure may be self-imposed by pilots who have developed the mental expectation that operations should be conducted a certain way. This type of social pressure many be internalized due to widespread beliefs and cultural expectations or may occur within single individuals due to personnel principles and past experiences. The following quote describes how an interviewed pilot felt internalized social pressure to comply with ATC, and therefore attempted to prioritize the ground controller's instruction despite the limited capability of the aircraft. This resulted in improper task prioritization, an unstable approach, and a go-around.

"We were going into Las Vegas and coming off of the arrival, they wanted us to keep our speed up … it was faster than what was typically normal for that segment of flight in the segment of the flight. We were, we were on the ILS [instrument landing system] ... and so they wanted us to be going faster than what we typically would like to go fast, that fast at, and that close to the runway. So, we tried to comply with, with what they wanted ... So, we were heavy, a bigger airplane that's harder to slow down. and so, what ended up happening is we had to go around because we were too fast, and we weren't stable at a thousand feet. We were, we weren't configured properly for the landing ... So, it was ineffective task management. We were trying to prioritize what the ground controllers wanted over what the airplane was capable of doing".

Quote 31. Social pressure to comply with ATC can make it difficult for some pilots to prioritize effectively.

5.6. Taskload and Task Saturation

Taskload is the mental demand imposed by the task or tasks a pilot needs to perform, while workload is defined as the subjective experience of the task's mental demand (Hilburn & Jorna, 2000). The reason these two terms are differentiated is because the actual mental demand or taskload may be different from an individual's subjective experience of the mental demand. For this work, pilot references to taskload and workload are reported together, and task saturation is explored as the result of an increasingly complex task

environment. A pilot may be described as "overloaded" when they can no longer complete tasks, and multiple factors may be the cause. Task saturation is a specific situation when the number of tasks a pilot needs to complete exceeds their mental capacity to complete tasks and causes a state of high workload.

Interviewees described experiencing task saturation in several different contexts. The most common was as a result of inclement weather, particularly on arrival and approach, where weather increases the number of tasks and task complexity. Forty-two interviewees discussed that weather creates a challenging task environment; four interviewees had the perspective that when there is a complex operating environment that includes changing conditions (e.g., weather or an emergency), the tasks for the pilot flying and the pilot monitoring to manage the flightpath increase and the resulting taskload can saturate both pilots. One interviewee below described a situation in which they were first officer on a flight to Boise, and the crew had no choice but to fly through an un-forecasted thunderstorm. The captain was pilot flying, and the interviewee was pilot monitoring. The interviewee referred to preparing the aircraft for the approach and landing, and they struggled to get all the tasks that they needed to get done while flying through an unexpected thunderstorm at night and monitoring the turbulent environment in which the captain was trying to hold the aircraft straight and level. As they came into land, the interviewee was scanning for the runway. They saw that while the runway lights were on, they could not clearly see the runway, and they realized then that the aircraft's landing lights were off. As a result of being task saturated, both the interviewee and captain inadvertently shed formerly completing the descent checklist they would normally have completed at 18,000 feet.

"It was at night and… unforecasted storms popped up in the summertime around Boise, it's pretty common. And we got a flash of lightning… there's a huge thunderstorm in front of us, and we're on a descent into Boise, going through 20,000 … we want to deviate to the right, but we can't, because there's military airspace… we're going through. And so, the captain is trying to fly the airplane, just basically hold it straight and level. And we're getting bounced around. I'm trying to get landing numbers. This is right in the descent phase when you're getting the weather and setting up for runways and I was getting overloaded. We got the things we needed to get done, except when we were coming into land, once we were through it all, I'm looking for the runway. The lights are on the runway, but we can't see the runway. And I look up and she doesn't have any of the landing lights on. And I realized at that point we didn't run the descent checklist, which you normally run at 18,000 feet. Because we were so overloaded and she's trying to fly the airplane that we went through 18,000. And by the time we got out of it, we're on the approach. And it was about 200 feet before we realized we'd never ran the checklist. Everything was set up fine, but we never ran the checklist, and the lights weren't even on."

Quote 32. Complex operating environments with changing conditions (e.g., weather) can increase the number of tasks and task complexity, which may lead to inadvertent task shedding.

Besides weather, the introduction of new tasks by ATC was another context in which pilots may become overloaded or task saturated, particularly if the tasks are during a demanding situation (e.g., if the preplanned flightpath is changed during certain phases of flight, such as a runway change late in the arrival or being vectored off a complex procedure and then vectored back on to resume published procedures). This is discussed under the section "Interruptions, Disruptions, and Distractions" as well, as these types of situations also typically interrupt existing tasks. A couple of interviewees also commented that complex instructions from ATC can lead to momentary instances of task saturation and potential for error as they try to memorize or record the instructions while performing other tasks. The interviewee quoted below discussed that multiple, similar numbers is particularly problematic.

"[ATC] gives a sequence of numbers… climb to this altitude, turn to this heading, maintain this airspeed… That actually might be the worst or the biggest example [of a complex instruction that harms task management]… if there's a lot going on and they give you complex instructions with multiple numbers in it, that's a recipe for disaster because now you're confusing a heading with an airspeed. [For example] turn to 150 or turn right heading 150, climb to 10,000 feet and you know, fly an airspeed of 200. And now you start getting those numbers mixed up and you climb to 15,000 instead of 10."

Quote 33. Complex instructions from ATC can lead to momentary task saturation and potential task management deficiencies and vulnerabilities.

Several interviewees noted circumstances in which either they or their fellow crewmember took on additional tasks that went beyond their role as either pilot flying/pilot monitoring or captain/FO, leading to an imbalance in task management and contributing to task management deficiencies or vulnerabilities. The motivations or reasons behind taking on additional tasks differed depending on each unique situation. In Quote 15 in the section on "Barriers to Crew Communication", the interviewee was pilot flying. When the pilot monitoring struggled to recall how to modify the flight plan in the FMS to go direct to a fix, the interviewee attempted to do the pilot monitoring's task. They did not effectively communicate this to the pilot monitoring, and while it did not lead to task saturation, it did disrupt their task management. In another example below, the interviewee was flying with a captain who had less experience with a heads-up display (HUD). The HUD was needed for the crew to land at an airport with low weather, and the interviewee coached the captain through how to use the HUD. However, the interviewee became task saturated in attempting to complete their tasks as FO, pilot monitoring, and assisting the captain with the use of the HUD, while responding to the captain, who was using non-standard callouts. Finally, in Quote 35 below, the interviewee discusses a scenario where the captain oversped the flaps while trying to manage and perform some of the interviewee's tasks related to clearing traffic on their side of the aircraft. There are potentially other factors contributing to overspeeding the flaps; this is just one potential factor.

"*The weather was really low, and we had to use the HUD. He [the captain] didn't know how to use the equipment… he's the only one that has access to that equipment on his side. So, I was having to try to talk him through how to use his equipment and do all of my tasks. I'm sitting in the right seat … he was making nonstandard calls … I was so task saturated … I had a hard time accomplishing my own duties.*"

Quote 34. Performing additional tasks beyond role (e.g., as FO and PM) in a complex operational environment (e.g., weather) can lead to task saturation.

"*On takeoff, we oversped the flaps because we got a radio call about conflicting traffic on my side of the airplane. I was doing my prescribed pilot monitoring tasks, and it was my job to clear for that traffic on my side, and the captain had a habit of trying to do my job and his, and so he ended up overspeeding the flaps. That ended up snowballing because [we were] unable to think through strategically of all the tasks that we now had to do.*"

Quote 35. Performing additional tasks beyond role (e.g., as Captain and PF) in a complex operational environment (e.g., high traffic) can lead to task saturation.

5.7. Pilot Aeronautical Experience

Pilot aeronautical experience includes a pilot's total flight hours and the quality of those flight hours. Quality is important for developing expertise, where quality can refer to the accumulation of hours under different operational conditions, circumstances, and complexity (e.g., as a flight instructor, corporate pilot, during poor weather, at difficult airports, multiengine, night instrument metrological conditions, etc.). differences in aeronautical experience could be considered an individual difference. Other individual differences are covered in the next Section "Individual Differences." Experience is important to task management because when pilots are overloaded, they will shed tasks based on their own experience, skill, and risk management of the situation. There are also rare malfunction cases where no checklist exists, or there are multiple failures that involve multiple checklists and complex situations. Pilots will mitigate the associated risk in these cases based on their experience, knowledge, and skills (PARC/CAST, 2013). In the

interviews, interviewees discussed how experience can help pilots develop task management proficiency and the effects on task management when there is a disparity in experience between crew members.

Interviewees with more operational experience described that detecting and adapting to a fellow pilot's abilities is an important skill for task management because working with someone who is still learning or still gaining confidence necessitate changes to how tasks are managed and allocated. It can also lead to the more experienced pilot needing to take on more tasks. In the quote below, one of the interviewees who was a captain discussed how they can recognize fairly quickly that their FO may need more support. As a result, the interviewee described that they may allocate more tasks to themselves that may be the FO's tasks normally, and that they also may need to be less reliant than they might otherwise be on the FO. This can mean that more experienced pilots must be even more proficient in task management when flying with less experienced pilots.

> "*When they're new and they're unfamiliar or uncomfortable with the airplane or their position… I end up realizing fairly quickly, I'm going to have to take the bull by the reins… They do a good job of training us on that, but sometimes you have issues with that. And so, I just realized at that point, okay, I'm going to have to be more alert and I'm going to have to probably load myself up a little bit more than what I normally would have."*

Quote 36. More experienced pilots may adapt to less experienced crew by taking on more tasks.

Another interviewee described a situation with a new FO. This example is indicative of several contributing factors to task management, but some of those factors highlight the effect of experience. It was the FO's first day in a B737; they were the pilot flying, and the interviewee was the pilot monitoring. The interviewee was reading the checklist that configures the aircraft for landing, and the first item was related to configuring the speed brakes. The FO thought when the interviewee called out the checklist item, the interviewee wanted the FO to use the speed brakes. At that point in time, using the speed brakes would be in direct violation of the aircraft operating limits. The interviewee recognized by the FO's response that the FO was saturated and was having challenges potentially prioritizing tasks. The interviewee was able to intervene and help manage tasks to reduce the FO's load.

> "*It was his first day in a 737. He was flying the aircraft into San Antonio and just the process of getting the aircraft configured for landing per normal aircraft operating rules and [airline operator] rules [was overwhelming]... I was reading the checklist. And the first step is speed brakes. Well, he was so overwhelmed by what was going on flying the airplane that he thought I was telling him to use the speed brakes, which was a violation of the operating limits with our landing flaps. So that's when I knew, okay, he's not prioritizing the task of flying the airplane, assessing his airspeed, assessing where the aircraft's going… I had to intervene."*

Quote 37. More experienced pilots can help detect when less experienced pilots become task saturated and intervene to help manage tasks.

When there is not a disparity in experience, this can create an effective task management environment. However, there are occasions where it can lead to complacency (see Section "Complacency"). In some circumstances, pilots with similar experiences can have difficulties managing their tasks. For example, if both pilots have the rank of captain, pilots acting as captains are accustomed to communicating as captains and thinking and managing tasks as captains. Their recent experience has ingrained a certain set of tasks in their mind, and they may struggle to adjust to the tasks they would do as an FO. One of the interviewees discussed an experience where the flight crew struggled to manage tasks effectively because they were both captains and adjusting to a different role took more cognitive effort than the pilots were accustomed to exercising.

"*Most of the problem was … there were two captains flying… task management was a little bit confused because everyone was trying to be captain. Meanwhile, there is one captain, of course. But it's very difficult…The task management was overlapping, and a few things were done twice. Meanwhile, they forgot to do something else, because, of course, if you think as a captain, the tasks that you normally do as a first officer are not simply in your mind. You have to stop and think about it.*"

Quote 38. Task management challenges may arise when a pilot whose recent experience is as Captain takes on the role of FO, as their recent experience means they are used to communicating, thinking, and managing tasks differently.

5.8. Individual Differences

People differ in their personality traits, cognitive abilities, experience and expression of emotion, attitudes and beliefs, social behavior, and other psychological characteristics as a result of diverse backgrounds, cultures, genetics, and many other factors. These variations are referred to as individual differences and can be observed across a wide range of dimensions and contexts. In the interviews, pilots commented on individual differences frequently as a potential contributing factor to task management deficiencies and vulnerabilities. The three most commonly referenced individual differences that impacted task management were differences in personality traits (e.g., traits such as extroversion, conscientiousness, neuroticism, openness, agreeableness (Roccas et al., 2002)), differences in social behavior, and differences in behavioral tendencies or work styles. Social behavior in the interviews was related to how pilots viewed, perceived, interpreted, and understood interactions with other pilots and cabin crew. Behavioral tendencies or work styles can be closely related to personality traits.

Personality traits can influence how individuals accomplish tasks. For example, both introverts and extroverts can value collaboration and communication; however, an extrovert may tend to communicate more frequently and may be more likely to solicit collaborative input from a teammate than an individual with a more introverted personality type. Individuals with different personality traits may not always work well together due to differences in communication styles and interaction preferences (Barry and Stewart, 1997). Interviewees mentioned several circumstances where differences in personality traits hindered task management. In the quote below, an interviewee with more extroverted personality traits mentioned how working with someone who has a more quiet and reserved communication style can hinder their ability to work together. This can impact task management when communication is needed to efficiently execute and allocate resources, such as an in emergency.

"Let's just say you've got somebody in the cockpit that just isn't a talker. They … just kind of go off in their own little world or they just look out the window… if a situation does pop up, whether it's an emergency or even something that's not an emergency, but we've got to run through various checklists… if you're not real comfortable communicating with the guy, it can definitely present a barrier … Like, did I, did I offend you somehow? Did I, do I smell funny?... So, that [lack of communication] presents its own distractions in and of itself … The best description I've ever heard is… it's like taking a multi-day road trip with somebody you've never met, and you have to trust their driving ability."

Quote 39. Communication and task management can be affected by personality differences and crew pairings (e.g., introverted PM with extroverted PF).

Individuals who possess a determined or persistent personality type may establish methods and routines for performing tasks. They may resist changes to established workflows and promote "their" way of accomplishing tasks. This can impact task management in two ways. First, individuals with forceful and persistent personalities can be challenging to work with which can impact task allocation and task performance. Several interviewees spoke about challenges working with pilots who were resistant to change. In one quote provided below, the interviewee was the FO, flying with a captain who had a specific strategy for performing the descent. The interviewee found it challenging to work with this captain. They felt they had a valid recommendation for the flightpath, but the captain was unwilling to listen.

"*There was one captain I flew with who was notoriously difficult to fly with. It had to be his way or the highway. It left no room for anything else, and his way… it was acceptable, it worked, but it was inefficient and very rigid … we're setting up for a descent… [and]… we have to build it the exact way he wants it built, even though there was many other ways to do it that would actually make it more efficient, a more efficient descent, an easier descent to slow down. It just, everything would have been a little bit easier had you just adjusted, like, your angle of descent… he has to have it his way because that's the only way he's ever done it … He couldn't experiment. He couldn't do anything that would be a little bit outside his comfort zone.*"

Quote 40. Determined or persistent personality types can make task management as a crew more challenging.

Similarly, some pilots may have exaggerated beliefs in their own capabilities. This can be detrimental because the pilot may build incorrect mental models of how they expect to perform in critical situations.

"The scariest pilots or crew members I ever fly with that they think they're more capable than they really are and then they build expectations and then they start believing whatever they see they want they make whatever that they have in their mind a reality and you're like no we're you're high or you're low or this is not working out, you know."

Quote 41. An individual pilot's self-awareness of their own knowledge, skills, and abilities can impact task management as a crew.

Secondly, task management may be impacted if individuals with determined or persistent personality types become inflexible or rigid in how they perform tasks. Quote 40 highlights this, in that the interviewee suggests that the captain they were flying with could not perform the descent any other way as they had become too used to doing it one way. This is the FO's perception of the captain's actions, which is a limitation of this work. However, this perception highlights a potential task management deficiency, as an individual's determination to accomplish tasks only one way could lead to the inability to adjust or dynamically adapt in a new or novel situation. In the quote below, another interviewee describes an experience where the interviewee, acting as FO, informed the captain their clearance was available when the captain was ready for it. The captain responded that they needed to restart their flows as a result of the FO's interruption. Restarting a flow from an interruption is a task management strategy that can be effective; however, the FO's perception was that restarting the flow completely as a result of the FO's actions was a sign the captain was too rigid in their methodology for performing tasks. The captain's response was so surprising to the interviewee that it was distracting to them. This highlights how differences in personality traits as well as behavioral tendencies or work styles can hinder how pilots work together to complete tasks.

"*I said, hey, you know, we have the clearance ready whenever you're ready for it. And it just threw him for a loop. He was like, oh, I was right in the middle of my flows. Now you distracted me, and I got to start all over again. So, it was like… just I mean, yeah, I get it, but… it was so rigid that it was distracting in its rigidness.*"

Quote 42. The ability to be adaptive and responsive to interruptions is different for different pilots, may be a potential task management deficiency, and can be distracting to pilots with different perspectives on adaptability.

While the rigid method to completing a task may be from persistent personality types, there are also situations where frequently and long-term use of mental models result in aversion to change their method or perspective. The pilot in the following quote describes this phenomenon and the resistance to changing their processes for task management and expectations of how the aircraft of airspace operates.

> "*By the time you get to fly at this level, even flying airplanes for a while, you have a methodology, you have a mental model already set as to how you break down what it is you have to do in the cockpit. And anybody who comes in and goes, hey, try this is probably going to meet with a little bit of resistance because, hey, this has been working for me for a long time now, so.*"

Quote 43. Mental models can become overtrained and rigid, which makes them harder to change.

Behavioral tendencies or different work styles was mentioned by several interviewees as having a potential impact on task management. For example, one interviewee discussed that some pilots are very proactive, almost to the point (from the interviewee's perspective) of being too proactive. As a work style, the interviewee described how some pilots will want to prepare for and brief the approach two hours before they will start to descend, and as a result, this can lead to doing tasks multiple times. From the interviewee's perspective, this is potentially a vulnerability as it creates extra work. This example also indicates differences in a crew's shared mental model, where the two pilots may have different perspectives on when to prepare for the arrival and why they might to want to prepare when they each think they should. This can impact how the crew manages these types of tasks.

> "*There's some people who just like to be the PDS, which is the Pilot Doing Stuff. They're doing stuff because they're bored. They're wanting to do something. And so, they load up the whole airplane …[while] we're still climbing. We got two-hour flight ahead of us… Why are we doing this right now? I think that that's poor task management … what happens if our fuel burn is a little different than what we planned and now actually landing numbers are faster than what you put in*"

Quote 44. Pilots have different work styles and perspectives on when to accomplish tasks, which can affect task management.

Several interviewees described the idea that some pilots have an "artificial urgency" to do something, or they may put unnecessary pressure on themselves to "rush." While this is also related to time perception (see Section "Perception of Time and Time Management") and could also be a result of social pressure (see Section "Effects of Operational and Social Pressure"), an underlying component is a potential behavioral tendency to be action-oriented, make quick decisions and act swiftly. This behavioral tendency may lead to task management deficiencies and vulnerabilities.

> "*Sometimes we pilots have this artificial urgency to do something. And this is the reason why I think pilots pull the wrong engine. They crash in a perfectly good airplane or, because it's like this cumulative factor, right? We're adding artificial urgency to a scenario that's not really that urgent.*

Quote 45. Some pilots may have a sense of artificial urgency. This can come from other factors (see Section "Effects of Operational and Social Pressure" and Section "Perception of Time and Time Management), but also may be a behavioral tendency to rush, to be action-oriented, make quick decisions, and act swiftly.

5.9. Fatigue

Fatigue is a physiological state characterized by diminished mental and physical performance, often resulting from extended duty hours, irregular sleep patterns, and the cumulative effects of multiple flight segments (Caldwell, 2012). Fatigue can impair cognitive functions such as attention, memory, and decision-making, leading to slower reaction times, increased potential for errors, and decreased situation awareness. For pilots, fatigue and the effects of fatigue can affect task management in several ways. The interviews highlighted that one contributing factor of fatigue to task management deficiencies and vulnerabilities was in the execution of tasks, with fatigue leading to misreading or misinterpreting instruments, failing to adhere to standard operating procedures, or missing communications from ATC, which could then snowball into other issues with task load and task saturation. For example, the below quote describes an interviewee's experience where their fatigue developed from tiredness, weather, and flying with a new pilot. The interviewee was the pilot flying and due to fatigue, they were inadequately monitoring their flightpath and

passed their final approach fix. Their pilot monitoring alerted them; however, the interviewee felt that the PM's communication was unclear which, when fatigued, added to the interviewee's task management challenges. It is possible the PM's communication was unclear because they also were fatigued and/or potentially because they were a newer pilot and still developing communication skills (see section on "Barriers to Crew Communication").

> *"The crew was very tired. …. And I was the pilot. Once again, I had a newer co-pilot. And I was flying in. It was super bad weather. And we had passed the final approach fix for decent and the co-pilot kind of mumbled something and I was like, 'yeah, well they want us to maintain this until' and then I looked down and I was like 'oops' so. Of course, then I had to like, get back on going so pretty quick, but that's that would be a, you know, inattention on my part based on fatigue and then the other crew member helping out. But it was… It was this weird kind of mumble like instead of like 'hey, we're past the final approach fix, start your descent'"*

Quote 46: Pilots may drop tasks when fatigued, such as frequency of their scan when monitoring the flightpath.

Eight interviewees mentioned the impact of fatigue on task management and that the effects of fatigue gradually build over time, for example over the course of multi-day trips. Correspondingly, pilot ability to manage tasks may correspondingly degrade. Fatigue can arise from demanding airline schedules, long working hours, and complex operational conditions such as weather. In Quote 47 and Quote 48 below, two interviewees describe a difference in task management performance when they feel well-rested versus at the end of a trip. One pilot discusses their ability to handle emergencies may be degraded, implying their ability to manage tasks could be diminished.

> *"Schedules, early mornings. Long days… Fatigue will also affect task management. It's 10 o'clock in the morning, you had a good night's sleep, and this is the first part of the day, and you have to go with the emergency right out of the gate - you're probably in your best game! [But] if it's seven [or] eight o'clock at night, you've been off since five o'clock in the morning and you are on your last leg going into an overnight flight after experiencing delays and maintenance and weather and all that. And you know what? Oh, my gosh, I'm beat. Probably not the best time to handle an emergency."*

Quote 47: Task management of emergencies may be more effective when the pilot is well-rested.

> *"You add in fatigue … again, poor task management… You've been on those days where you've worked four days in a row and you're flying… You're going, chasing the clock, and you've got a couple of days of cumulative, not great sleep. And now you're on a 14-hour duty today, arriving somewhere at night. And all of a sudden, the task management is not the same as departing on a sunny day out of Phoenix, well rested."*

Quote 48: Fatigue can gradually build over time and may gradually degrade task management performance.

5.10. Stress

Stress is a complex human response that can be acute or chronic. Acute stress can arise from immediate challenges such as adverse weather conditions, technical malfunctions, or high traffic volumes, while chronic stress may result from ongoing pressures like irregular schedules, time zone changes, and organizational demands (Cullen, Cahill, & Gaynor, 2021). The two quotes below describe stress arising from high traffic environments and the higher workload pilots may experience when in a crowded airspace. In the second quote, the interviewee mentions that stress for the pilot can increase when ATC is task saturated, as may happen in a high traffic environment, and the pilot is uncertain about whether they are where they are supposed to be but cannot easily ask.

"If the radio is crazy busy, and it's just nonstop and you're in a critical phase of flight, it does make it more challenging and more stressful because you really have to really actively listen at the same time as you are trying to control the aircraft, communicate with your crew, and manage your energy."

Quote 49: High-traffic environments with congested radios during critical phases of flight can increase pilot stress.

"Frequently, we have task saturated air traffic controllers who start mixing up call signs, mixing up instructions, and it creates a doubt as to where you're supposed to be in space. And if others know where they're supposed to be in space… then that doubt introduces a huge stress component inside the cockpit. And then if you try to clarify—which we train people to do when they're not quite sure—you can't get a word in edgewise, and people, pilots get frustrated, and they start making radio calls over each other and nobody can hear anything. It's a big mess.

Quote 50: Stress from high-traffic environments with congested radios can increase when ATC mixes up calls signs and pilots experience decreasing situation awareness.

When stressed, as in the two examples above, the interviewees discussed how that stress can affect task management by impairing cognitive functions such as attention, memory, and decision-making. For example, when stressed, pilots may experience tunnel vision and reduced situation awareness, compromising their ability to prioritize and execute tasks efficiently. One interviewee described how pilots may miss checklists items when stressed.

"I have been in cockpits before where the stress level is high. And it seems to be if one or both pilots are stressed, they tend to miss things on checklist."

Quote 51: Stress can result in pilots inadvertently dropping tasks (e.g., missing items on the checklist).

The experience of stress can lead individuals to develop different methods for coping with stress, or strategies and behaviors to manage and mitigate the impact of stress. One method for pilots to cope with stress is to become task-oriented, where their attention becomes hyper-focused externally on the task at hand (Tianchai, 2022). Becoming task-oriented can be a beneficial coping mechanism, but interviewees did describe a tradeoff. By becoming externally focused, pilots may lose some degree of self-awareness; that is part of the coping process. Several interviewees described scenarios where they experienced stress and coped by becoming task oriented; two examples are provided in the quotes below. The first quote is about a challenging approach flightpath. The interviewee gave additional context to the quote that the approach was at night, and they were feeling overloaded as was the FO. It was only after landing that they could acknowledge the extent to which stress had impacted them. In all examples, the interviewees were able to manage their tasks, so it is unclear if this coping mechanism contributes to task management deficiencies and vulnerabilities by generating a form of tunnel vision or if it is beneficial in how it may compartmentalize the emotional impact of stress.

"We were coming in from a direction where it was hard to navigate into the runway. And we did [it]. We flew in and we landed… I was uncomfortable with it (e.g., was overloaded). And when we got on the ground, the FO was very uncomfortable with it… we got on the ground and the FO goes, I was in the red there... And I felt the same way he did."

Quote 52: Pilots may cope with stress by focusing on tasks, a form of tunnel vision and acknowledging stress and high workload after the experience which generates it.

"I started getting a big vibration in the elevator and I really got scared because there's nothing you can do if you get a structural failure. You're just in it for the ride. There's nothing you can do, but I pulled the power back. I reduced my descent. I reduced my airspeed … When I got on the ground, then basically stress kicked in… I sat there and just didn't know what to do, couldn't even open the door up, and oh my goodness, I just, I thought I was gonna die."

Quote 53: Pilots may cope with stress by focusing on tasks, a form of tunnel vision and acknowledging stress and high workload after the experience which generates it.

Interviewees discussed how stress can arise from other sources not pertaining to the flight deck or aviating, such as personal issues. The effects of this stress remain the same with stress affecting task management by impairing cognitive functions such as attention, memory, and decision-making. In the first quote below, the interviewee describes how, due to being stressed about personal issues, they were not actively engaging in the tasks they normally would do in preparation for a flight, such as thinking about weather and checking the maintenance status of the aircraft (Authors note: this could also be identified as distraction or rumination; see Section "Interruptions, Disruptions, and Distractions"). As a result, the interviewee describes getting behind and feeling the stress level go up, as they felt like they were wasting time. A snowball effect occurred on their ability to manage tasks and on their psychoemotional state. In the second quote, the interviewee was flying with a captain who was stressed about their personal finances. The interviewee felt the captain was distracted and unfocused, resulting in effects on their ability to manage tasks, and increasing the taskload for the interviewee.

"I went to work with personal issues on my mind. So, I did not start anticipating tactics and strategies on the way to the airport, like for instance, checking the weather… the maintenance status of the aircraft. I didn't do [these activities] because I was thinking about personal things. So, you get to the airport without doing this. Then you meet with a colleague, sort of expecting him or her to have done that. Which didn't happen [in this case]. So, we found ourselves at the very last minute dealing with this sort of information and obviously, Murphy's law, it was not our luck. We had maintenance issues, weather issues. You start lagging behind in the decision making, and you chase yourself, wasting time, getting nervous, the stress level goes up, and so on."

Quote 54: Stress due to personal issues can distract from tasks (e.g., planning and preparation). This can lead to getting behind, further impacting task management.

"[I] was flying with a captain that had just bought a house… and he started having to worry about his finances… There was one trip that he was so stressed out… I mean, you literally had to snap your fingers to get the guy's attention … felt like I always had to look over his shoulder to make sure he was doing his job, you know, how it was expected to be done… having to re-verify he did in fact do whatever it is he was supposed to be doing… it was almost like flying single pilot."

Quote 55: Stress due to personal issues may affect a pilots' ability to manage their tasks, and other pilots may have to compensate, increasing their own taskload.

5.11. Startle and Surprise

Startle has been described as an involuntary reflex that occurs very quickly along with a physiological reaction to a sudden and intense stimulus (e.g., loud noise, vibration). Startle may briefly disrupt basic motor responses, information processing, and interrupt pilot thought processes and associated tasks (e.g., checklists) (Diarra et al., 2023). The startle reflex happens so fast that the reaction occurs unconsciously. In addition to the startle reflex, some descriptions of startle include an emotional and cognitive response, which can be a conditioned, behavioral response such as stress-related enervation of the sympathetic nervous system (Rivera et al., 2024); however, the stress response has been established as a separate mechanism and may occur independently (Finseth et al., 2024). S*urprise* is an emotional response to an unexpected event that comes from a mismatch between mental expectations and reality (e.g., an expected event which did not occur, an expected event may have occurred at an unexpected moment, or an

unexpected event occurs) (Rivera et al., 2014; Horstmann, 2006). As with startle, surprise may result in stress, but the stress response is a separate mechanism and may occur independently (Finseth et al, 2024).

Startle can temporarily immobilize an individual and result in tunnel vision. After startle reflex activation, performance of basic motor responses is automatically and involuntarily disrupted for approximately 3 seconds, and tasks involving complex motor responses can be disrupted for up to 10 seconds (Rivera et al., 2014). Attentional resources are attracted to the stimulus that caused the startle (e.g., flight event). Attentional tunneling (i.e., tunnel vision) can occur if the startle reflex evolves into a surprise reaction. This can happen if, as the operator attempts to understand the startle response, there is a mismatch between mental expectations and reality (Diarra et al., 2023).

Several interviewees discussed the effect of startle on task management. In the first quote below, the interviewee was the captain of a flight where they experienced a gradual loss of cabin pressurization. The altitude warning horn went off, causing startle. The interviewee discussed that actively being aware of not getting tunnel vision and mentally keeping their situation awareness helped; the interviewee felt that having performed similar maneuvers in the simulator had developed this meta-cognitive ability to keep from getting locked in on one attention-grabbing stimulus.

"[We had] a gradual loss of cabin pressurization…while flying [we] have an altitude warning horn go off, which means the cabin's gone above 10,000 feet and it's continuing to climb… we're sitting at cruise altitude, 33,000 feet, so the first thing is silence, then the warning… it's a lot of tasks you've got to prioritize… having trained for that maneuver several times in the simulator, I think, definitely helps prepare you to deal with that situation…you always have that startle factor, you know, that warning goes off, it's like oh what do we got here, oh [expletive]… once you get over the startle factor, and you know, don't get tunnel vision, and keep your situational awareness, I mean, I think that's the key to not get locked in on one thing."

Quote 56: Startle and surprise may result in tunnel vision, which can decrease situation awareness.

Another interviewee described an event where both pilots lost their flight management computers while in cruise. The interviewee describes being startled and how it took 3-5 seconds for them to realize the aircraft was in a stable state. In this example and in Quote 56, the interviewees described how the startle reflex disrupted their basic motor responses, information processing, and thought processes. In these two examples, startle did not contribute to task management deficiencies or vulnerabilities because the interviewees, together with their fellow crew members, actively prioritized aviate and consciously thought about not getting tunnel vision.

"We had both of our navigational computers [FMCs] go out at 36,000 feet and it's, like, it startles you. There's a startling surprise there. You know, it's like 'Wait, what is it doing?' and it takes about three to five seconds for you to realize 'Okay, hey, the engines are still burning. We're still going in a straight direction. Hey, you're flying… we're not in danger of anything'."

Quote 57: Startle can temporarily immobilize the pilot.

Since startle and surprise are dependent on perception, pilots may have differing degrees of startle and surprise, even when experiencing the same stimuli or situation. One pilot may become startled whereas the other may not, due to differences in sensory perception. Similarly, one pilot may become surprised whereas the other may not, due to differences in expectations and perspectives of a particular situation. The below quote describes a scenario in which the interviewee was the FO, and as pilot flying, they experienced surprise when the captain accidentally deleted the approach while changing the runway and then had challenges re-programming the FMS. The interviewee was surprised when the expected event did not occur (e.g., the runway change was programmed) and an unexpected event occurred (e.g., the approach was deleted). For the surprised pilot, the incomplete approach began to attract attentional resources. This could have resulted in tunnel vision, but as with the two previous examples, a degree of self-awareness had them

thinking about not getting locked in and they went back to looking out the window to fly the aircraft. They dropped the task of entering the approach in the box and asked the captain to give them vectors instead.

> *"We were trying to change runways. I was the FO, and the captain actually deleted the approach. And finally, I look outside, and I go, 'You know what? Let's just, give me the flightpath vector, and we'll just land the airplane.'… The startle and surprise part was when I looked down and realized that he couldn't get the approach into the box … All I remember is realizing that he's having difficulty getting the proper approach in the box, starting to feel myself get sucked into that process. And then something tugging at my head going, 'Don't do that.' And then I look, look outside, and just go back to just flying the airplane."*

Quote 58: Pilots may be surprised by other crew members actions and resist orientation of attention.

Events that increase operational complexity, such as changes to the flightpath as a result of changing weather or ATC instructions, can also result in surprise. This surprise can contribute to task management deficiencies and vulnerabilities. In the first quote below, the interviewee discusses how they have an expectation for vectors that will clear them onto an approach, and when reality does not meet that expectation, meaning ATC introduces an unexpected change, it can take them a minute to adjust to that change. This could potentially disrupt task management. The second quote describes how rapidly changing weather conditions may generate surprise, which may also disrupt task management.

> *"OK, we're nearing the approach. I'm probably going to get two or three vectors that I'm going to be cleared onto the approach. It's when you get something from them [ATC] that's an unexpected interjection from the normal flow of the flight that can kind of you know, I guess startle or surprise you there for a second and take a minute to catch up and process with what they were asking."*

Quote 59: Pilots may be surprised when ATC introduces a change to an approach and the pilots' expectations differ from reality.

> *"Maybe, all of a sudden, you're expecting the weather [to be] nice, and all of a sudden, you're coming in on the approach and oh, hey, now the visibility is down to a quarter mile. Like, whoa! Where'd that come from?"*

Quote 60: Pilots may be surprised by changes to environmental conditions and the pilots' expectations of the environmental conditions differ from reality.

5.12. Effects of Domestic and International Airspace Operations: ATC

Five of the interviewees came from European operators and twenty-eight participants had experience of international airspace. In discussions on task management, several interviewees stated differences between domestic and international ATC impact task management. There is a consistent framework for communication, procedures, and expectations domestically, and pilots familiar with this framework can anticipate and respond efficiently to ATC instructions. International ATC involves navigating diverse regulatory environments, communication styles, and procedural norms, which can vary widely from one country to another.

One potential contributing factor to task management deficiencies and vulnerabilities that interviewees discussed pertained to the varied phraseology. Several interviewees mentioned that when flying internationally they must pay additional attention to how clearances are requested and how clearances are provided. For example, in the quote below, the interviewee discussed how being cleared direct may be preceded by 'route direct' in countries outside the United States and that pilots need to be careful and clarify clearances provided to them. This interviewee emphasized that it is on the pilot to be sure. This responsibility and the increased uncertainty that may come from traveling internationally can potentially increase task load and generate a more challenging task environment for the pilot.

"They do things a little differently outside the United States. For instance, just about any other place other than the US, if you are cleared direct to something, it should be preceded by the word 'route direct' … We're used to saying in the US, 'Can we proceed direct?', meaning from where I am in a straight line direct to where I want to go... So, sometimes you have to be really, really careful. It's incumbent on you to say, 'Are we clear present position direct?' instead of 'route direct.'"

Quote 61: Differences between international ATC phraseology and domestic ATC phraseology as well as the uncertainty that may come from these differences can increase pilot task load when flying internationally.

Similarly, several interviewees mentioned that the listening task can be harder internationally due to differences in accents and levels of English proficiency among international controllers. In the quote below, the interviewee discusses how the task load increases for all of the crew. Because comprehension may be more challenging, both pilots are cognitively engaged in trying to understand what the air traffic controllers are communicating to the aircraft.

"The dialect sometimes is very difficult to understand … It required two people to be listening all the time … there were three of us on the flight deck all the time … So, all three of us had to be listening to what was going on, you know, and sometimes "What did he say? What did he say?" You know, it could be difficult on occasion."

Quote 62: Challenges with listening to and understanding international ATC can result in additional taskload for pilots when flying internationally.

Task management can also be made more difficult when the air traffic controllers speak the local language, and the pilots do not know that language. Several interviewees spoke about how not understanding what the other aircraft are saying to the controller can increase the complexity of their tasks by decreasing the situation awareness they would normally gain through listening.

"We fly to an international airport like Charles de Gaulle or Madrid with thousands of airplane, and they are talking in Spanish with each other in Madrid or they are talking in French in Paris. And as a pilot, as an airline pilot, it's important also to understand what's going on around you, what's the other plane doing"

Quote 63: Changes in language usage by ATC when flying internationally can increase task complexity and taskload.

"Losing situational awareness is not a comfortable feeling … when I go down to Mexico and most of the time, they're speaking in Spanish …. it's one of those situations where I don't know where they are, or what they're doing, or where they're going."

Quote 64: Changes in language usage by ATC when flying internationally can contribute to decreased situation awareness.

Outside of language and phraseology, another potential contributing factor to task management deficiencies and vulnerabilities that interviewees discussed was the difference in expectations regarding the role of the pilot versus the role of ATC in other areas of the world. Several interviewees stated that in some countries, the expectation is that ATC takes a less active role, and this can be an adjustment from flying in the U.S. For example, in the interview quotes below, the pilots described differences in the mentality and expectations between flying with ATC in the U.S. and flying in Mexico, South America, Africa, and Russia. According to the interviewees, pilots are expected to be more proactive, and they cannot rely on ATC as a backup in these areas, which can increase the pilots' task load and also change the tasks pilots need to manage, in that the pilots need to push more communication to ATC than they may be used to doing.

"In Mexico … they assume that you know what you are doing. And if you ask them to descend to an altitude, they assume you know you're going to navigate around any potential terrain, and they will most likely clear you to do it… They have minimum altitudes that they'll send you down to … So yeah, internationally… your task loading goes up. Because in the U.S., you kind of get more reliant on air traffic control and your confidence with them and I don't think I have that as much on an international trip."

Quote 65: Differences in expectations of interactions between pilots and ATC in Mexico can increase pilot taskload.

"They're not really handholding at all. There's a lot of times where you'll get to the limit of the clearance you have and not know what is going to happen in the next five miles … you have to prompt them like 'OK, hey, after this spot, what's the plan? What are we going to do here?' It's very common in the States to where you already know that information well ahead of time, … a lot of times [internationally] it's much more reactionary. So that's much more tactical."

Quote 66: Differences in expectations of interactions between pilots and ATC in South America can increase pilot taskload.

"In … Africa, North Africa, the Middle East, former Russia, some areas of Eastern Europe, Asia, it is a problem, because it's more often the pilots telling ATC what we need to do than the other way around. So, they don't seem to be managing traffic … you're oftentimes you're on your own, you're alone. Africa, for example, Africa, sometimes they don't even answer the radio … to fly for an hour or more without actually talking to anyone because there's nobody on the other side."

Quote 67: Differences in expectations of interactions between pilots and ATC in Africa and other areas of the world can increase pilot taskload.

"There's a hierarchy in Russia where an air traffic controller would never tell a captain, because he's much higher in the hierarchy, what to do. So, in that situation, the Russian pilot will tell the air traffic controller when he's going to land and the Russian controller would say, 'That's okay'."

Quote 68: Differences in expectations of interactions between pilots and ATC in Russia can increase pilot taskload.

5.13. Effects of System and Operational Complexity

System complexity and operational complexity can impact task management in a variety of ways. Several interviewees describe situations they had challenges programming the FMS. These challenges may have arisen due to differences in aeronautical experience, aircraft proficiency, or skill level; however, these examples also support how system complexity can be a causal and contributing factor to task management deficiencies and vulnerabilities. The following quote describes such a situation, where the first officer was pilot flying and they were unfamiliar with the aircraft FMS, having just come from a different aircraft. They did not sequency the box correctly and did not intercept final. This resulted in a go-around. They then experienced a snowball effect on their ability to manage their tasks.

"I didn't sequence the flight management computer correctly just because it has a different, I guess, methodology behind it compared to the other aircraft that I had come from … on our approach, I didn't sequence the box to the next waypoint in front of me, whereas on [other aircraft he had flown], that's not really an issue. But effectively, we didn't intercept final correctly, and we ended up being high on final and then performing a go-around. While on the go-around, ATC vectored us very close to the final approach fix, and basically said maintain a specific altitude, which for our position was way too high. The captain was telling me we needed to descend, we needed to descend. And I was like, well, we haven't been cleared to descend yet. We're still maintained 3000 until established. We're not yet established on this approach … So, then he reached out to ATC and was like, hey, can we get lower? …. [I got] behind the airplane initially on the first approach by not sequencing the proper fix. And then it had a snowball effect after that."

Quote 69: Unfamiliarity with aircraft systems can complicate task management.

Even when the pilot may be familiar with the FMS, interviewees commented that due to the complexity of the FMS, it can surprise them when it functions differently than they expect. This can result in tunnel vision (see Startle and Surprise). The below quote describes a pilot who loses situation awareness of the aircraft while attempting to program the FMS, and instead shed the task because of its complexity in the limited time environment.

> *"I call it getting lost in the box, you know, cause, … you're heads down and you're trying to figure out like 'Okay, well, how do I program?' And then you look up and you're like 'Oh, the runway is right over there. Oh crap. I'm… you know, I'm high or I'm …my air speed's off, my altitude's off. I'm not ready to land' as opposed to like 'Okay, you know what? This now is no longer helping me in my task management. It's hurting me … this is now a level of complexity I don't need.'"*

Quote 70: FMS programming complexity can lead to loss of situation awareness.

Airspace procedure design and use is another form of operational complexity that may affect task management. These issues may arise flight procedures, airport configuration, airspace management, or other operational tasks. Several interviewees described task management issues with airspeed restrictions. In the following interview quote, the interviewee provides the example of Charlotte airport which has speed restrictions that are challenging to accomplish with certain aircraft. In addition, the interviewee states that the departure and arrival paths are in a configuration that may result in resolution advisories which may surprise pilots who are inattentive, impacting task management.

> *"Charlotte STARs and SIDs and their airspeed restrictions… somehow, they hit best glide on all the airplanes, somewhere around 210 knots… If you're at 210 knots, it's really hard to idle descend at any sort of decent rate. You're going to have to get boards out, you're going to have to get flaps out or something. And likewise, on departure, the arrival path comes right over the departure path. Basically, you're turning into another airplane, and you have the potential to get resolution advisories routinely, unless you're really paying attention. So, and I'm sure that pisses off both the controllers and the pilots at the same time….so it's… just extra workload."*

Quote 71: Airspeed restrictions and unusual flightpaths may increase pilot workload.

Pilots also mentioned ATC can provide airspeed instructions that increase operational complexity, especially if the airspeed instructions are challenging to adhere to, given the performance characteristics of the aircraft. The instructions add complexity that can increase pilot taskload. For example, the following quote describes speed restrictions on crossing altitudes which increases pilot tasks and time to complete tasks.

> *"They built arrivals with these speeds to make crossing altitudes... I mean, some of the speeds are 280, and then they slow you to 250, but still invoking the cross, you know, the arrival altitude. But they think you can just flip a switch and go from 280 to 250 and still stay on your descent profile. But now it's sort of ups, if you want to say task management, it ups your, you have to think and process, 'Okay, I'm going to need speed brakes.' Are we going to, you have to do some mental math and think about the time needed to do this task and maybe even advise ATC that we're going to be unable this altitude at this fix due to your speed restriction. What do you want, speed or altitude?"*

Quote 72: Speed restrictions on crossing altitudes may increase operational complexity.

In other situations, pilots describe conflicts that can arise from airspace procedures that differ from other airports. In the following quote, an interviewed pilots describes how pilots following the aviation regulation slow down automatically when in the New York without contacting ATC because aviation regulations state aircraft should slow down to 200 knots below class B airspace. However, in New York it is procedure that pilots also contact ATC to notify them that a speed change has occurred because ATC in New York tend

to keep aircraft fast. The interviewee described that contacting ATC prior to slowing adds complexity and taskload but if not performed can exacerbates taskload by resulting in verbal disagreement between the pilot and ATC, who may each perceive they are following procedure correctly.

> *"In the New York area, for instance, if you slow to 200 knots below their Class B, all the approach charts tell you like notify the controller before you slow down…. and New York's like the only place they want you to go fast… but the aviation regulation states you got to go 200 below the class B, so guys will slow down automatically. They'll neglect to tell ATC because they're following the rule. And ATC is like, you just screwed up my entire traffic flow to this super busy area. Like, why'd you do that? And then they have this discussion over the radio"*

Quote 73: Differing airport procedures can add complexity to operations.

The type and frequency of communication may also differ between airports. Pilots form expectations in the form of mental models, which help them anticipate what type of support they will receive from ATC. If these expectations about ATC differ from reality, this adds a layer of complexity on aircraft operations. The following interviewed pilot describes how some airport ATC will provide a different level of support than other airports, which pilots need to be cognizant of when entering airspace.

> *"You go to San Francisco, LA, New York, Atlanta, Chicago, you, they're, they're going to tell you what to do. Slow to 210 knots turn right into three, six, zero to descend and maintain 5,000 feet. You know, and they're going to say it. It's going to be like, you know, but when you go into some other airport, if you go into Charleston or Nashville, you may not get that. And they're not going to tell you to slow up and you better be prepared."*

Quote 74: Differing communication and support for airport ATC.

6. MITIGATIONS AND EFFECTIVENESS

Six categories of mitigations were identified as described by the interviewees. A summary of the mitigations is provided below. Sections 6.1 through 6.6 provide detailed breakdowns of the mitigations, along with example quotes from the interviews. Where possible, the effectiveness of these mitigations, as perceived by the interviewees and interpreted through qualitative analysis, is also detailed.

Effective communication is important mitigator for task management deficiencies and vulnerabilities. Procedural communication (e.g., briefings) and task-based communication can reduce the likelihood of tasks being mismanaged or not completed, decrease stress and workload, support the building of shared mental models, and prevent task overload. Communicating effectively is a skill, and it includes the ability to communicate socially. While social conversation can be causal and contributing factor to task management deficiencies and vulnerabilities, social conversation is also a mitigation. Engaging in social conversation builds rapport between pilots, allows for both pilots to get a sense of the other pilot's personality, background, and capabilities, and builds a communicative, open environment conducive to task management. Social communication can prevent a non-communicative environment which fosters poor planning, poor task allocation, hinders task execution, and increased potential for misunderstandings.

Policies and procedures can mitigate many of the causal and contributing factors to task management deficiencies and vulnerabilities including those related to communication, operational and social pressure, task allocation, and fatigue. Interviewees mentioned specifically procedures that establish a standardized language, division of tasks, concrete confirmations by both pilots of changes to the flightpath (e.g., altitude and speed changes), encourage use of dispatch in the case of changes to planned flight routes, establish that both pilot monitoring and pilot flying confirm they both heard what ATC communicated (if one pilot is uncertain, they ask for a clarification), go-around policies that do not assign fault to the pilot, and policies that ensure pilots are not rushed can help mitigate task management deficiencies and vulnerabilities. However, there was a lack of policies or procedures on how to handle interruptions or disruptions during

normal operations. Interviewees noted this could be an effective mitigation for task management vulnerabilities during pre-flight preparations.

Five different **prioritization strategies** were discussed being helpful for mitigating task management deficiencies and vulnerabilities. Aviate-Navigate-Communicate-Systems (ANCS) was perceived as an extremely effective strategy for high-level task prioritization. However, interviewees noted that pilots may benefit from additional strategies to help manage sub-tasks and make decisions regarding task prioritization when there is increased operational complexity. Staying ahead of the aircraft was a close second to ANCS as a task management strategy; interviewees listed the following activities or elements they focus on to stay ahead of the aircraft and that this helps with task management: planning during pre-flight and before taxi, effective briefings, robust shared mental models, task delegation, effective CRM, and maintaining situation awareness, especially with tasks like ATC instructions. Another strategy heavily utilized was threat evaluation; this strategy relies heavily on experience and subjective assessment, however. Task shedding did not appear to be commonly used as a conscious, beneficial strategy for task management. Finally, personalized reminders was a strategy some interviewees felt can help with task management and mitigate potential deficiencies and vulnerabilities.

Metacognition involves an awareness of one's own thought processes and an understanding of the patterns behind them (Mayer, 1998; Pantiwati, 2013). Several **metacognitive strategies** or skills may help mitigate task management deficiencies and vulnerabilities. The Green-Yellow-Red strategy provides a useful, simple framework for pilots to recognize and articulate workload and taskload, which is necessary to mitigate becoming overloaded. However, because it is a metacognitive strategy, awareness of one's own thought processes is needed in order to exercise the strategy, and as an individual becomes increasingly loaded, this can be challenging. Several pilots did mention that actively being aware of not getting tunnel vision and mentally keeping their situation awareness can help prevent overload and attentional tunneling.

Making time was another commonly cited strategy for managing tasks. This strategy can mitigate potential task management deficiencies and vulnerabilities in many circumstances. However, to make time, one needs to be aware of time. Effectiveness of making time as a strategy is dependent on providing pilots with the metacognitive skills of (a) building a sense of time, (b) being able to recognize situations where the time they personally need to execute tasks may not align with time available, and (c) being able to recognize when the time to execute tasks may differ between crew members (e.g., captain may be able to perform tasks faster than FO).

Nine pilots referred to the "Swiss Cheese" model as a way of thinking about tasks, potential errors, and if there were mitigations for any threats or errors they may encounter. As a highly conceptual framework, it does not provide direct guidance on how to trap threats. Those pilots who mentioned this model relied on it as a means for thinking how task management threats or errors might be trapped and whether there were mitigations in-place. For example, they may recognize they are fatigued, the threat that this represents to task management, and assume that having a second qualified crew member on board is a potential mitigation.

The interviewees described both **strategic and tactical strategies** for managing tasks as potential mitigations for task management deficiencies and vulnerabilities. Strategic strategies focused on proactive planning and tactical strategies tended to involve reactive task management. Understanding the interplay between these two strategy types is crucial for developing comprehensive task management training that can equip pilots with the skills for applying both methods when necessary.

Simulator training was perceived as extremely effective for mitigating task management deficiencies and vulnerabilities by giving pilots the opportunity to practice strategies and develop time awareness in safe environment. Interviewees felt that performing high-stress, high workload maneuvers in the simulator can

help develop the meta-cognitive ability to keep from getting locked in on one attention-grabbing stimulus when it occurs in the aircraft. However, even in the simulator, the task environment is not realistic and task management strategies learned in the simulator will need to be adjusted to reflect reality.

6.1. Communication to Mitigate Task Management Deficiencies and Vulnerabilities

Communication

Communication can serve as an important mitigator of task management vulnerabilities and deficiencies, when performed effectively. Thirty-eight pilots stressed the importance of clear and timely communication specifically in the context of task management. These interviewees emphasized that communication may be the most key component to effective task management. Twenty-six pilots felt that they should not be managing tasks in isolation but completing tasks as a crew, and knowing when and what to communicate is what enables them to work as a crew. Two pilots discussed that the sterile flight deck rule is critical to task management in helping to minimize non-essential communication during those critical phases of flight. They went further to say that there are phases, such as preparing the aircraft for departure, when managing distractions like non-essential conversations may be useful and could help task management.

Communication can be task-based, or it can also be social, for the purpose of building rapport and learning how the other individual thinks. Fifteen interviewees talked about how social communication can help maintain alertness during periods of low workload and contribute to a crew's shared mental model. While social conversation may seem trivial, it is important for building a shared mental model necessary for flight deck task management. However, pilots must balance the topical conversation versus operational duties so that the conversation does not distract or interfere with aviating the aircraft. One pilot described how conversation over a few days of flying with a new pilot helped build a shared mental model, allowing them to better predict the other pilot's behavior.

Quotes included:

- *"Well, the biggest strategy is also the hardest to execute [and that is] communicate. Communicate, communicate, communicate. 'Hey boss, this is my plan'."*
- *"[The pilot has] to say "Yes, we're doing that" or "No, we're sticking to what we did before."*
- *"That's probably the one thing that may help the most. It's good communication."*
- *"And communicating, so there's never any doubt what's going on in the other person's head."*
- *"Any good leader [Captain] is going to create an environment that allows them [the FO] to communicate."*

Effectiveness:

Communication is essential in mitigating task management deficiencies and vulnerabilities. However, communication is also complex. The sterile flight deck rule and Advisory Circular (AC) 120-51E (2004) on "Crew Resource Management (CRM) Training" support task management in supporting effective communication, highlighting the importance of interpersonal skills, and emphasizing the factors which effect communication. However, fifteen interviewees discussed that communication can be challenging, and that there are still gaps and barriers. It is not always easy to ensure that communication is effective and is being performed in such a way that it benefits task management.

Briefings

Briefings are a specific time for pilots to communicate; briefings help set expectations regarding each pilot's tasks, the timing of tasks, and task management strategies in the event of a non-normal episode. Interviewees described briefings as crucial to task management because they ensure both pilots know what is happening. The described benefits of effective briefings included the following (Note, the number of

interviewees who referenced these points are included below. These were not the same individuals across all points):

- Helps build a shared mental model (12 interviewees)
- Mitigates threats (2 interviewees)
- Reduces stress and negative emotions (2 interviewees)
- Minimizes or even can eliminate surprise (2 interviewees)
- Leads to more effective time management (10 interviewees)
- Solidifies expectations regarding task balancing (10 interviewees)
- Leads to more effective threat and error management (11 interviewees)
- More effective CRM over the flight because better understanding of other pilot's abilities (4 interviewees)
- Promotes proactive behavior (9 interviewees)

Interviewees discussed that giving an effective briefing is a skill. Five interviewees desired briefings that were concise but detailed and tailored to the experience, knowledge, and skills of their fellow crewmembers. However, four interviewees had experienced briefings that were not at this level of quality.

Interviewees stated that most components of the briefing provided value for task management. There were specific components of the brief that can especially support task management. These components included:

- What's wrong with the airplane (2 interviewees)
- Threats, runway changes, weather conditions, and expected/predicted threats (4 interviewees)
- Capabilities of the aircraft (e.g., gates, taxiways, runways, etc.) (2 interviewees)
- Discussion of responsibilities (5 interviewees)

While briefings can mitigate task management deficiencies and vulnerabilities, briefings themselves must be handled within the context of task management. For example, four interviewees mentioned that handling interruptions during the briefing is a skill. Two interviewees stated that stopping the briefing during an interruption (e.g., an ATC instruction or event) is critical to task management in order to avoid missing an instruction or making a mistake. Yielding to flying the aircraft first is vital (4 interviewees). Resuming the briefing is additionally a skill; when to resume and how the briefing is resumed is important to fluid and effective task management. Finally, briefings should be performed when pilots have a low task load.

Some relevant quotes from interviewees include:

- *"Briefings are huge… [briefings] are a huge part of… staying ahead of [the aircraft]"*
- *"[several flight crews] mishandled go around events. And usually, one of the things that was always noted was that they did not brief the go around ahead of time."*

Effectiveness:

Interviewee responses confirmed that effective briefings reduce the likelihood of tasks being mismanaged or not completed, decrease stress and workload, support shared mental models, and prevent task overload. Briefings which are the most effective for task management are performed during periods of low taskload whenever possible, stopped appropriately for interruptions, resumed appropriately, and are tailored to the crew members.

Establishing Shared Mental Models

Communication is the backbone of shared mental models. Shared mental models are described as situations in which all pilots have a shared understanding of what the aircraft is doing, a shared understanding of what the other pilot(s) is doing, and a shared understanding of what the other pilot (s) will and will not do. Shared mental models are established through communication, both verbal (e.g., through speech) and non-verbal

(e.g., through behavior such as gestures). Shared mental models are critical to effective task management as each pilot has a mutual understanding of the tasks to be done, responsibilities, goals, and potential outcomes.

As a mitigation to task management deficiencies and vulnerabilities, ten interviewee responses indicated that managing tasks was most effective in a flight deck environment that fostered teamwork and open communication, where briefings were high-quality, and communication was continuous and iterative (meaning the crew regrouped and re-briefed when receiving latest information or taking new actions). The content of their responses indicated that these components led to more robust shared mental models, and this led to a smoother division of tasks and timely execution. Pilots with robust shared mental models "speak the same language" and are able to complete tasks more efficiently and effectively. The mental model can be established beforehand to help with task prioritization in tactical situations, as described by the following quote.

"So then in the moment, you're relying on that sort of tactical approach, your own kind of skill and, and task prioritization to get you through when, if you would have just talked about it beforehand, you know, you would at least have some mental model of, you know, what is the order and sequence instead of having to try to figure that out in the moment while you're also flying and controlling the aircraft."

Quote 75: A prior mental model helps to effective act in tactical situations.

To facilitate establishing shared mental models, two interviewees discussed using strategies to establish common ground with their fellow crewmember. For example, icebreakers that build rapport can help generate a flight deck environment of open communication. Pilots also attempt to build similar mental models by learning about their co-pilots past experiences, in order to predict how their co-pilot will react in the future. The following quotes describe the pilot's communication strategies.

"You know, just the typical get to know you small talk, and generally that'll lead to something that you find a common ground on, hey, I like to fish, I like to boat, I like to golf, whatever ... sometimes people will be flying with another pilot, and they just won't get along at all. And there's just not a synergy. They won't develop like a flow. And it throws the whole cockpit off, like all the decisions you make, all the task management. And where I'm seeing this is when I'm hearing about this, what it kind of reminds me is, it's kind of this trial and error period where you're trying to figure out what they're thinking. And so, you're testing it little by little, trying to figure out, well, like, you know, what are they going to do next?"

Quote 76: Rapport with the other pilot is critical to task management.

"You get that conversation; you get to learn. Oh, where did you learn to fly? What did you do before this? And then you can understand, oh, you were a F-18 pilot during the Gulf War, and you did all this other stuff, and now what you're doing makes sense because that's what you did when you were an F-18 pilot ... you start building those mental models of what other pilots are like and what they do."

Quote 77: Conversation helps to develop a mental model to predict the other pilot's behavior.

A shared mental model can also be built of how both pilots view the operational environment. The following quotes describe how the shared mental model is a continuous process that is updated by gathering information, then communicated about between team members, and then updated again. This shared mental model is important for quickly executing tasks while maintaining a shared understanding.

"He's [the captain's] talking to dispatch. He's talking to the flight attendants. He's, he's trying to coordinate whatever he's coordinate. And then at some point you come back together, and you try to develop that shared mental model again. And I update on him on what's been going on with air traffic control and our vector and our altitude. And then, and then we, then we together, work the checklist and then they detach again. And there are certain things that I'm trying to help out to be able to get ahead that he's not aware of. So, you have to bring him up to speed and he has to bring you up to speed on. And, and again, you're constantly trying to make sure that you've developed, you maintain that shared mental model, what's going on with the cockpit, what's going on overall."

Quote 78: Shared mental models need to be updated through frequent communication.

"It starts with that brief, it starts with the verification of points, all those things procedurally and going down and being together. I like that term that we use all the time… the shared mental model, like, that is huge. I mean, if he's thinking something completely different, his mind and the expectations there and it's wrong, but I notice it's wrong, but it's right in his head, he's just going to go down that path, you know? So, we have to continually talk about it."

Quote 79: Shared mental models need to be updated through frequent communication.

"We build that shared mental model. So, we don't like to brief exact things like, "Hey, when we land, we're going to get off on Tango 5 and we're going to make a right on-" because then you have something in your head that's like, okay, that's definitely what we're doing. Rather, we'd like to brief 'we're landing to the South. We could get either runway. Let's brief both of them. This is our primary runway. And we should, based on the landing data, unless I land long, we should end up somewhere over here and we will have a runway to cross. And there are some hotspots we need to look out for.' So, we're not feet to the fire that that's our plan but we have some shared mental model of expectations and threats from whatever we're about to do."

Quote 80: Shared mental models need to be updated through frequent communication.

Differences in operational experience can lead to challenges establishing a shared mental models. As described previously in Section "Pilot Aeronautical Experience" and Section "Individual Differences", pilots who may have less experience or training may not have as robust of a mental model about flight situations. To mitigate these challenges, one pilot describes in the strategy of tailoring information to the crew members experience level while forming the shared mental model to increase accuracy and robustness.

"So, knowing somebody's experience level and tailoring that briefing or that shared mental model to that person is- it's very important because if I have a guy who's just … [new]… I know they don't know how to do it. … you just kind of tailor a lot of those briefings to the level of experience that that person has, … I try to bring back the basic math. I'm like, hey, remember in private pilots. Like the three to one rule still applies, whether you're flying a jet or a small aircraft. … we have that shared mental model again that, 'Hey, we're both going to make these points and we're going to navigate this airplane safely to a landing.'

Quote 81: Tailoring the information communicated in a shared mental model can help when crew members have aeronautical experience disparities.

<u>Effectiveness</u>

Establishing a robust shared mental model is effective in mitigating task management deficiencies and vulnerabilities. Robust shared mental models lead to:

- More balanced tasks
- Reduced risk of task overloading
- Efficient task completion due to deeper understanding of the other pilot's actions
- Reduced risk of incomplete or missed tasks

- Greater task completion

Robust shared mental models are more easily established when crew members use a standard language, have common experiences (in training, in the aircraft, at the operator), communicate effectively with the appropriate level of detail, establish common goals, have complimentary personalities, similar backgrounds and/or they establish common ground in the face of diverse backgrounds.

Crew Resource Management (CRM)

Crew Resource Management (CRM) is a set of training procedures and principles meant to enhance safety by improving communication, teamwork, and decision-making among flight crew members. CRM refers to the effective use of all available resources: human resources, hardware, and information. Pilots were overwhelmingly positive about CRM and the role it plays in facilitating effective task management. For example, interviewees attributed task allocation between pilot flying and pilot monitoring to effective CRM practices and found this extremely valuable for caching errors, mistakes, and managing the flightpath. In addition, CRM is strongly associated with effective communication in the flight deck and the concept of establishing a robust shared mental model. Several interviewees noted that CRM is fundamental to task management; otherwise, it would be easy to get overloaded and make mistakes.

Effectiveness:

Effective CRM relies heavily on communication. Interviewees noted that the CRM effectiveness is affected by personality differences, how pilots appear (based on interviewee perspectives) to practice CRM, cultural differences, and flight decks with two captains. Primarily these factors can affect how information is communicated and the quality of the communication.

6.2. Mitigations in Policies and Procedures

Based on interviewee comments, policies and procedures can support task management by providing a standard language that can help crew members build shared mental models, providing a framework for the assignment and responsibility of tasks, and ensuring that pilots know they have resources available to them for managing tasks. Furthermore, policies and procedures can mitigate task management deficiencies and vulnerabilities by ensuring everyone understands their tasks, supporting pilot tasks in abnormalities, and facilitating full awareness by all pilots of the circumstances.

Examples of policies and procedures interviewees specifically mentioned as facilitating task management included those that establish standardized language, concrete confirmations by both pilots of changes to the flightpath (e.g., altitude and speed changes), encourage use of dispatch in the case of changes to planned flight routes, establish that both pilot monitoring and pilot flying to confirm they both *heard* what ATC communicated (if one pilot is uncertain, they ask for a clarification), go-around policies that do not assign fault to the pilot, and policies that ensure pilots are not rushed at the gate, on the ground, or in the air.

Interviewees also described policies and procedures regarding the division of tasks and that this supports task management. For example, one pilot discussed explicit assignment for who has abort authority as well as procedures for communicating the status of the engines and thrust settings ensure there is no confusion regarding abort authority and the status of the aircraft. Another pilot discussed having clear announcements of who is flying the aircraft is essential, and that sometimes this can be dropped. Another example was in the case of an abnormal event. Five interviewees mentioned policies or procedures that encourage the first officer to manage the aviate task while the captain handles the abnormal event. All five interviewees that discussed this were in favor of this method for managing tasks; however, there were caveats. Several interviewees noted this role assignment can be complicated because there may be an abnormal event where the captain may be more suited to being the pilot flying. One interviewee noted that the captain should

remain as the pilot communicating to ATC, and this task should not be handed over the first officer with the aviate task.

Checklists are a type of procedure that provide a specific set of tasks to be verified or performed, ensuring that the flight deck crew completes critical tasks consistently, accurately, and in compliance with standards and regulations. Interviewees noted that checklists can mitigate task management errors by standardizing tasks, providing a shared language, and establishing a structure. There are several aspects to checklists however that must be considered.

One interviewee noted that the timing of checklists is vital to effective task management. For example, a checklist may get interrupted or may even be missed if a frequency change occurs at the same time. When frequency changes will occur cannot necessarily be predicted; however, consideration should be made regarding when checklists should be executed in case there are other tasks that are co-occurring, as this can be potentially problematic. Similarly, two interviewees noted that checklists can introduce redundancy that is (from their perspective) unnecessary and leads to avoidable task loading. Two other interviewees noted that they have policies for restarting checklists if they were interrupted. However, they felt this also could hinder task management by adding additional tasks and time. They stated that restarting the checklist was not always a practice that was followed for this reason.

Finally, some policies and procedures may encourage the use of automation to as an option to relieve pilots from workload. For one interviewee, this can be helpful, because it can free some cognitive load that can be used to handle other, more strategic tasks (e.g., looking at weather, planning for the arrival and approach)

Sample comments from interviewees regarding policies and procedures:

- *"The policies and procedures help us all understand what our tasks are… and everybody does it pretty, you know, pretty much by the book."*
- [Regarding policy of confirming altitude changes] *"the hand stayed right there… until the pilot monitoring … acknowledged climb… honestly, it was one of the most effective things."*
- *" Our company dispatch, of course, is always available to communicate with… I reach out to them, and in any given scenario, that's not going as planned, to get input."*
- *"If both* [pilots] *didn't hear it, I'd say eight times out of ten, you have ATC repeat it. If only one person heard it, you know, company policy is, you know, let's verify it so we both hear it."*
- *"It's no fault go around policy here, if you're not comfortable with the approach, you go around. Nobody's going to hassle you about it. That's a really good thing."*
- *"If you're not ready to go, you just tell the gate, we need a few minutes, and they walk away, and they don't bother you. So, I mean, nobody pressures you here to rush."*
- *"The FO's main job is to fly the airplane and communicate with ATC and then that frees you [the captain] up to prioritize your tasks based on time management."*
- *"The captain puts himself out of the loop* [of the situation] *if he chooses to remain the pilot flying as opposed to managing the situation."*
- *"We typically tell captains to not give the role of talking to ATC to the FO to reduce the risk of miscommunications during emergencies."*
- *"On our takeoff roll, the pilot who's performing the takeoff will announce takeoff, and then he or she will remove their hands from the thrust levers. Then the captain will have their hand on the levers because they have final abort authority. That's one of the procedures to avoid any confusion on abort authority. And then starting a timer, if we utilize a certain engine condition for takeoff, where the engines are temperature-limited, for that takeoff, in addition to ensuring that those thrust levers are put in the correct thrust detent, a callout is "thrust set"… we both know I have done it*

because I put the thrust levers there and he has or she has said, "hey, I've confirmed that they're at the appropriate takeoff position".

- *"Whoever's flying says, we'll say 'my aircraft.' So, we establish who's flying the aircraft."*
- *"They want you to use the FMC as much as possible … We have procedures that* [direct you to be] *at the highest level of automation… for as long as possible ... That allows you, when you're not hand flying the airplane and the autopilot's doing it, then you can think a little more clearly. It's a little more difficult when you're hand-flying the airplane to think and to manage tasks*."
- *"They're very good at encouraging that kind of communication and keeping it standard. … no matter who I'm flying with, we do it the same way every time."*
- *"Always flying by standards. You fly the aircraft a certain way, standards the way the company wants you to fly it… not by making things up."*
- *"Division of tasks based on crew position, and then so we have a foundation of kind of what's expected."*

Effectiveness

Interviewees noted that some policies and procedures have been effective in mitigating task management deficiencies and vulnerabilities. Policies and procedures which facilitate the creation and maintenance of a shared mental model between crewmembers (e.g., through callouts and communications), support task load management (e.g., balancing assignment, making assignment and authority clear), and reduce or eliminate pressures (e.g., time pressure) are effective in reducing task management errors.

There are however policies and procedures that are less effective. For example, policies and procedures which do not appropriately balance the task load between the right and left seat can harm task management. Three interviewees noted that procedures regarding callouts can harm task management. Removing callouts can result in fewer opportunities to establish a shared mental model. On the other hand, specific call outs or requiring many callouts may result in unnecessary task loading. One interviewee noted that they felt too many callouts is also problematic and methods for allowing non-verbal acknowledgements can be a suitable alternative (e.g., a hand gesture to acknowledge a flight mode change).

"[calls that] make you have to do mental math or unnatural responses at places that you may not normally be thinking… it's like a double-edged sword … It can help a lot, but if you're forcing the crew from a policy or procedure standpoint to be performing some sort of call out, it can get to the point where two people are kind of talking over one another because the triggers are happening simultaneously, which will lead to, of course, confusion in the flight deck if you're trying to speak over one another and also, you know, if you have some sort of call out, that's the triggers, I guess, kind of ill-defined. It increases the mental task loading of you trying to figure out when am I supposed to say this? And then you're focusing on verbalizing something when you should be focusing on, of course, you know, the primary control of the aircraft."

Quote 82: Policy or procedures for callouts may be an onerous mitigation, as it may increase the mental task loading.

One interviewee noted that they felt there was a lack of policies or procedures on how to handle interruptions or disruptions during normal operations, and that this could be an effective mitigation for task management vulnerabilities during pre-flight preparations. During pre-flight, interruptions from the gate crew, flight attendants, or maintenance are common. Strategies for managing those interruptions may be left up to the individual pilot and this presents an opportunity for tasks to be missed or dropped.

Policies and procedures exist to mitigate fatigue. Often this involves completing a report that is submitted to request recovery days. This report is separate from sick leave. Interviewed pilots stated that these policies are not widely believed to be beneficial, the procedure is onerous, and many do not believe these policies are effective in mitigating flying while fatigued.

> *"There's a procedure that you have to go through when you are fatigued. And that procedure is a little onerous. And it just makes it feel like they really don't want you to do it."*

Quote 83: Fatigue reporting is a mitigation, but procedure can be onerous.

One pilot mentioned that sometimes it not just the onerous reports, but also the pilot's previous experience that may have changed their perception on utilizing the fatigue reporting procedures. The below quote describes how a negative experience led the pilot be less likely to use this mitigation.

> *"You have to go in and fill out the fitness for duty report that, that you know outlines why you are fatigued or why you are sick. And sometimes the duty pilot says, 'well are you really tired?' ... these questions like that which makes you feel like, 'wow', it's just it's just a lot easier to just suck it up and go, which is what most people do."*

Quote 84: The onerous reporting process results in pilot choosing to fly fatigued.

6.3. Prioritization Strategies

Task prioritization may be one of the most important contributing factors to effective task management, with strategies for prioritizing tasks one of the key methods for mitigating deficiencies and vulnerabilities. The definition of task prioritization (or antonym, task misprioritization) is commonly associated with the comparison and selection of tasks to form an ordering or ranking to which attentional resources will be allocated relatively (Bishara, 2002; Chou & Funk, 1990; Colvin, 2000; Colvin et al., 2005; Stebel, 2005). Prioritization was discussed by every interviewee, and they described a range of methods for how they prioritize tasks. However, even with the strategies outlined, some interviewees believe that prioritization is primarily learned through experience. Procedure and strategies exist and can facilitate prioritization, but interviewees felt effective prioritizing can really only occur with knowledge gained through years of experience.

Aviate-Navigate-Communicate-Manage Systems (ANCS)

The strategy "Aviate, Navigate, Communicate, Manage Systems" is a fundamental principle in aviation used to prioritize tasks and manage workload. Interviewees stated frequently that aviating and maintaining control of the aircraft is the primary responsibility of the pilot. Aviating ensures the aircraft remains in stable flight and is the top priority at all times. After ensuring the aircraft is stable and under control, the next priority is navigation. This involves determining the aircraft's current position and planning the route to the destination. Once the aircraft is under control and properly navigated, the pilot should communicate with ATC and other relevant parties. Effective communication ensures coordination and the sharing of vital information. The last step involves managing the aircraft's systems to ensure they are functioning correctly. This includes monitoring and adjusting engines, fuel, electrical systems, and other onboard equipment.

In the interviews, twenty-one pilots discussed ANCS; they overwhelmingly considered the strategy a best practice that contributed to safer operations. Pilots stated that it helps them focus on flying the plane and building time to solve any issues. Some interviewees stated that under normal circumstances, aviate and navigate are frequently taken care of by automated systems, and they can focus on communication. Interviewees described that while communication is lowest priority, effective communication is vital to safety and task management. As a result, decision making is needed when using aviate-navigate-communicate to prioritize tasks in the moment. Communicating with ATC, dispatch, or their fellow crewmember may be crucial for situation awareness and coordination, and potentially for effectively executing the aviate task. In addition, communication ensures tasks do not get missed or forgotten, and both pilots maintain a shared mental model.

<u>Effectiveness:</u>

The interviews indicate that ANCS is extremely effective as a strategy for high-level task prioritization. However, pilots may benefit from additional strategies to help manage sub-tasks and make decisions regarding task prioritization, where some situations may benefit from tasks being addressed in a more nuanced sequence. Interviewees acknowledged that there is complexity in prioritizing tasks in some situations, particularly when communication may be vital. This suggests ANCS may rely on a pilot's training and experience. Finally, some interviewees noted that ANCS can lead to task saturation.

Being Proactive (Staying Ahead)

Eighteen interviewees described being proactive or staying ahead of the aircraft as a vital component to effective task management. Proactively planning for future events and executing tasks ahead of time was detailed as a strategic and very necessary part of task management. Being ahead of the aircraft ensures a healthy balance of tasks such that pilots are not saturated. Interviewees universally agreed that falling behind increases the likelihood of mistakes, errors, missing tasks, missing ATC calls, poor decision making, improper task allocation, and tunnel vision. Being proactive and staying ahead is a strategy pilots develop with training and experience, but it also is a strategy pilots need to actively practice, or they may risk falling behind. Experience can help an individual realize when they are falling behind. Some interviewees felt that the pilot monitoring should be working ahead of the aircraft while the pilot flying focuses on aviating, which they described as being more tactical.

To stay ahead of the aircraft, interviewees listed the following activities that can help: planning during pre-flight and before taxi, effective briefings, robust shared mental models, task delegation, effective CRM, and maintaining situation awareness. Interviewees referenced common situations or areas in which being proactive is needed to stay ahead of the plane. This included policies and procedures that can help facilitate proactivity and thinking ahead, standard operations, managing ATC communications, anticipating ATC communications, handling maintenance issues, and managing tasks on short routes. Being proactive is aided by low-workload phases of flight (like cruise) when it is possible to get tasks done ahead of time for future phases of flight (arrival and approach), positive crew factors and effective CRM, and good situation awareness, aided by Traffic Alert and Collision Avoidance System (TCAS) and monitoring radio calls.

> *"As the pilot monitoring, it's my job to anticipate what, since I'm monitoring, it's my job to anticipate what the captain needs… I try to do a mental inventory of like, "Okay, is there any tasks that I can accomplish now so that I don't have more to do later?"*

Quote 85: Anticipate what the captain may need in the future.

> *"You're trying to prepare as much as you can before you leave the gate. Because once you leave the gate, that's when everything starts rolling."*

Quote 86: Prepare before leaving the gate.

Perceived Severity

Prioritization was also described in terms of identifying the most immediate threat first, where pilots place the highest priority on what they perceive to be the most severe threat. Twelve pilots described this strategy for task prioritization, where actions to address the most severe threat are prioritized, often based on urgency of task and circumstances. In the following quotes, interviewees stated that they would focus on immediate threats during emergencies, and they noted that as a part of assessing the severity of the situation, one priority would be attempting to make enough time in order to work on tasks effectively.

"You know, you kill the closest alligator… It's perceived severity… I got to take out this one, this alligator… The reality is I'm not going to die from this three-foot alligator, but this 10-foot alligator that's 20 feet away, it's close, but it's not that close… It's a simplification of the risk-reward conversation. I got to address the things that are going to kill me the soonest and the fastest."

Quote 87: Perceived severity is used to prioritize the most urgent threat.

"You're launching off across the ocean and you have an engine fire. Your navigation problem is very low. And so, your fire is the biggest priority... The most immediate threat, what's going to hurt me first is the first thing I want to deal with."

Quote 88: Attention and priority is given to the most immediate threat.

"Prioritizing tasks and assigning, you know, I guess some level of urgency ... separate it almost into two categories, things that are, like, really threatening and things that are non-threatening."

Quote 89: Prioritizing based on threat vs. non-threat.

To determine what is an immediate threat, pilots described several evaluation criteria they would use to assess the situation:

- The nature of the threat
  - For instance, in the case of a cracked windshield, pilots treat it as critical, figure out if it is inner pane or outer pane. Depending on which pane leads to whether loss of pressurization is imminent and how critical the situation is and how quickly it must be dealt with.
  - Whether there is an impact on fuel and how much fuel they currently have to determine whether this aspect will generate a time limitation
  - How the threat may change with changes in the environment, phase of flight, or other changes
- Checklists, policies, procedures
  - Both for emergency situations and standard operations.
  - For standard operations, checklists have pilot work through critical tasks to ensure safety of the plane.
  - For emergencies, there will be guidance on assessing the situation's severity and what should be done to mitigate it. Often in the forms of Quick Reference Handbook (QRH) to get quick guidance on how to handle a situation.
- Experience
  - Based on their experience, assess criticality of the situation

Based on their assessment of the severity of the situation, interviewees stated that they would then:

- Decide which tasks to prioritize.
  - For example, in the case of the cracked windshield, if it is a severe crack, pilots will focus on getting the airplane safely to ground first. If it is a non-emergency crack, pilots could descend to a safe altitude and continue to their destination.
  - Determine if any tasks will not be completed.
  - Account for time severity of the situation.
- Determine and perform communications, in terms of brevity and who is being contacted.
- Strategize for potential scenarios that may impact the severity of the situation and proactively plan for and brief the risks.

Effectiveness:
While procedures and training can guide how pilots assess the severity of a situation, threat evaluation as a prioritization strategy relies heavily on experience and subjective assessment. Effectiveness of this strategy is going to vary significantly depending on the individual, their training, and their experience. This means that while this may be an extremely effective strategy for some pilots, it may not be an effective strategy for others.

Task Shedding

Task shedding is a strategy used by pilots to prioritize essential tasks and temporarily set aside or delegate less critical ones. This strategy helps manage workload and maintain focus on the most crucial activities to ensure safety and efficiency. Only two interviewees mentioned this as a strategy. Both interviewees referenced that they may not strictly shed the task but rely on the other pilot to help. It would seem that task shedding is not commonly used as a conscious strategy.

> *"Well, the first step to dealing with task saturation is recognizing you're task saturated, and ways of dealing with task saturation is trying to offload some of the tasks. I mean, if I'm task saturated, you know, I might, you know, I'm going to ask the other pilot; see if I can maybe offload some aspect of my workload."*

Quote 90: Pilots should be cognizant of their task saturation.

Effectiveness:
As a mitigation, the effectiveness (and risks) of shedding tasks was brought up rarely by the interviewees.

Personalized Reminders

Interviewees described using their own methods for remembering or managing tasks. These personalized reminders ensure tasks are not forgotten. For instance, pilots will put an object in an unusual location, clip their tie to the map clip, write a note (either in the FMS or on paper), turning displays down, and turn lights on/off, etc. Some of the reminders pilots referenced included:

- "*put(ing) the checklist in a different place in the cockpit to remind themselves they hadn't done it yet."*
- "*I used to always put my ring on my thumb when I was transferring fuel so I wouldn't forget to look up and close the transfer valve…you do something physical to remind yourself."*
- "*Some guys used to clip their tie to the map clip on the yoke to remind themselves of something. Yeah, just something physical that will stand out to you that's different when you look around and go, oh yeah, I was doing that.*"
- "*I had a guy that used to put an army man on the panel in front of the flying pilot to remember whose leg it was on a long flight. He goes, this is a leg man. It tells you whose leg it is.*"

Effectiveness:
Pilots who utilize these techniques swear by their effectiveness. Pilots who do not use these techniques criticize their potential for complacency and error.

6.4. Metacognitive Strategies for Task Management

Metacognition involves an awareness of one's own thought processes and an understanding of the patterns behind them (Mayer, 1998; Pantiwati, 2013). Metacognitive strategies for task management are strategies that involve an awareness of one's own thought processes in order to be exercised and when exercised have potential to mitigate deficiencies and vulnerabilities. In the interviews, interviewees referred to several metacognitive strategies that they believed helped with managing tasks.

Green, Yellow, Red Strategy

The "Green-Yellow-Red" strategy in aviation, also known as the "Green-Yellow-Red" concept, is a risk management and situation awareness tool used by pilots to categorize their workload and taskload. This strategy can also be used to categorize operational conditions or events based on their level of risk or urgency. The interviewees indicated that green signaled they are not saturated, yellow indicates some task saturation with the potential for becoming overloaded, and red indicates they are overloaded and overwhelmed. Utilizing the Green-Yellow-Red strategy, if a pilot recognizes they are in the yellow, they can then act which might involve leveraging one of the prioritization strategies described in the previous section on "Prioritization Strategies," such as slowing down, asking for assistance, or shedding tasks. Exercising this strategy means pilots need to be cognizant of their loading. If pilots are aware and able to categorize their workload and taskload as well as communicate that workload and taskload to their fellow crewmembers, this enables the crew as a whole to respond to tasks effectively. However, if a pilot is not aware and capable of categorizing their workload and taskload, this strategy may be less effective.

> *"It's a continual monitoring of the temperature that you're at … green you're not saturated, yellow you start to become saturated, red you're deep and so I use that as kind of a temperature scale of, how saturated am I starting to feel? As soon as I start to feel like I'm in the yellow, becoming a little more saturated, I'm starting to build some time and desaturate so that I can manage it better."*

Quote 91: Green-Yellow-Red strategy.

Effectiveness:

When one is overloaded or nearing the state of overloaded, being able to recognize and articulate one's state is necessary in order to act on it. The Green-Yellow-Red strategy provides a useful, simple framework for pilots to recognize and articulate workload and taskload, which is necessary to mitigate becoming overloaded. However, because it is a metacognitive strategy, exercising the strategy means pilots need an awareness of their own thought processes, and as an individual becomes increasingly loaded, this can be challenging. In analysis of responses, pilots appear to rarely mention being "in the green." This may be because this is the assumed state so fewer pilots try to acknowledge or recognize they are in the green. Recognizing that one is in the green offers opportunity to accomplish tasks that are better performed in low workload times. On the other end of the spectrum, pilots also appear to rarely mention being "in the red" until after the situation which put them "in the red" is over. Other pilots appear to recognize when a fellow pilot is in the red. Interviewees stated there are indicators such as the other pilot may cease communicating. However, if both pilots are in the red, as one interviewee discussed occurring to them, neither pilot may be able to recognize and communicate that they are overloaded.

ABCD Model

The ABCD model is a systematic strategy to managing and prioritizing tasks, risks, and actions. The acronym stands for Assess, Balance, Communicate, and Decide. Assessing involves gathering and evaluating information about the current situation, conditions, and any potential risks or issues. Balancing involves weighing the importance and urgency of pertinent factors, considering the resources available, and determining the best course of action. Communication is the clear and effective exchange of information among fellow crew members and ATC. Deciding involves making informed choices and selecting the best course of action for safety and efficiency, based on the previous steps of assessment, balance, and communication. .

Interviewees describe the ABCD model as a useful strategy for helping them to slow down and assess the situation, consider the resources available to them, communicate, and then execute, followed by a debrief. The debrief was discussed as a component of the ABCD model because the debrief incorporates feedback in an iterative process, where the pilots can then re-assess the situation and continue the cycle until the problem is resolved or all tasks completed.

Effectiveness:
This strategy can help pilots break down the decision making process into manageable steps and make more informed and rational decisions. As a framework, it can help with setting out and managing tasks. However, two interviewees noted that task saturation directly impacts the effectiveness of ABCD and in a realistic flight environment, one has to be practiced at utilizing the strategy for it to be useful when events move very quickly. The strategy can work well in a dynamic environment; however, extensive training in using the strategy to manage tasks and make sound decisions under pressure may be needed for it to be effective.

Making Time

Making time or slowing down is an essential strategy that fourteen interviewees referred to using to manage time and tasks. When using this strategy, pilots recognize that they need additional time to complete tasks and use knowledge that may come from training or experience to decide how they might "make time." Several pilots indicated that this is a strategy encouraged in training. Recognition of a need to slow down might occur when pilots realize one or both pilots are saturated or overloaded, there is an emergency or other threat where they can afford to slow down (e.g., landing gear is stuck), critical tasks have not been completed before entering another phase of flight, or the crew needs additional information to complete tasks that they do not have. One interviewee noted that "making time" as a strategy comes more easily with experience and confidence.

To "make time," several options, methods, or strategies exist, depending on the situation:

- Execute a go arounds.
- Request a holding pattern.
- Request a delayed vector.
- Slow down early on the arrival.
- Delay takeoff.
- Descend to a lower altitude.
- Tell ATC to standby to slow communication overload.
- Delegate tasks to other resources (e.g., dispatch)

Pilots made the following comments regarding making time:

- *"Making time … you can do that a number of ways. If you're on the ground, you taxi slower. If it looks like you're getting too close to the end of the runway and the other guy's not there yet just ask around to go over and hold somewhere […] In the air, you can ask for delay vector. You can ask for holding."*
- *"If I notice my FO is getting saturated, then I will slow us both down, pull over or whatever. It's important to make time."*
- *"I think operational experience is crucial in realizing that a situation should be slowed down or can be slowed down."*
- "W*henever we have something and somebody's trying to rush us… I'm the guy who's not going to release the parking brake and push back until I'm completely satisfied. And I have the capacity to do that now, whereas maybe 15 or 20 years ago, I didn't, because when you're young, might be a little more impetuous".*

Effectiveness:
Interviewees recognized that slowing down can have the following effects on task management:

- Enable more effective task management by giving the crew more time to complete tasks.
- Enhance safety by allowing crew to ensure tasks are done properly.
- Reduces likelihood of mistakes due to rushing
- Task desaturation (moving from red or yellow to green)
- Reduces likelihood of missed tasks

- Reduces strain on external crew or resources (ATC, dispatch, gate, etc.)
- Reduces stress during emergency situations.

Making time is a commonly cited strategy for managing tasks. Being cognizant of making time as well as methods for making time is trained at some airlines. However, the lesson of making time may not always transfer from one situation to another and may not always possible as a strategy, depending on the situation. Alternative strategies are also needed.

"Swiss Cheese" Model

Nine interviewees mentioned the Swiss Cheese model (Reason, Hollnagel, & Paries, 2006; Reason, 1990; Reason, 1997) for task management. As described by Reason and colleagues, the model is based on a metaphor that suggests multiple contributors (the holes in cheese slices) must be aligned for any adverse events to occur. Barriers in a system (the slices themselves) are intended to prevent errors that result in these adverse events.

Interviewees mentioned this model, because they felt that the model provided a good framework for how they thought about tasks and task management. For some pilots, it was the first way that they were taught about how to conceptualize errors, why procedures are important, and how to manage tasks to 'trap' errors. Interviewees suggested that the model provides guidance for formulating thought processes and can put them in a mindset where they think about potential contributors or "holes," which they can find useful for managing tasks. For example, there was an assumption that having a second qualified crew member on board was a potential mitigation for recognizing and trapping potential errors that the interviewee may make.

> *"For me, [the Swiss Cheese model] was a great visualization. Holes in the cheese lining up and procedures, experience, all that. I get it. That's the way I think."*

Quote 92: Swiss cheese model can help visualize the problem.

Effectiveness:

As a method for framing tasks and the importance of tasks, the Swiss Cheese model appears useful to some pilots. However, it is highly conceptual and does not provide direct guidance on how to trap threats and errors specifically, except through the necessary application of policies and procedures.

6.5. Strategic and Tactical Strategies for Managing Tasks

The task management strategies among commercial airline pilots revealed a distinct difference between strategic and tactical strategies. Strategic task management involves long-term planning and decision-making aimed at optimizing overall flight performance and safety. It encompasses activities such as route planning, fuel management, and anticipating potential challenges based on weather forecasts and air traffic patterns. In contrast, tactical task management focuses on real-time problem-solving and immediate decision-making during flight operations. This includes responding to sudden changes in weather, managing in-flight system failures, and coordinating with ATC for rerouting. The strategy allows pilots to prepare and mitigate risks in advance, while the tactical strategy enables effective execution of tasks in the moment, including quick, adaptive responses to dynamic and often unpredictable situations. Understanding the interplay between these two strategies is crucial for developing comprehensive task management training that can equip pilots with the skills needed for both proactive planning of tasks and reactive task management.

Effectiveness:

All pilots described using some form of strategic and/or tactical task management. However, the effectiveness of the strategies employed was difficult to assess subjectively as they varied situationally,

were subject to confirmation bias and were highly influenced by causal and contributing human factors. Strategic task management is fundamental for the pre-planning of the flight and division of tasks ahead of time. Tactical task management occurs in normal operations and in unforeseen circumstances. Tactical task management is important because it reflects pilot ability to respond dynamically to a changing environment and the ability to prioritize more urgent tasks. Some pilots believe that the amount of strategic and tactical task management needed is inversely proportional (i.e., the more of one strategy, the less need for the other strategy). While some pilots favored and used one strategy over the other more predominantly, other pilots stated that both strategic and tactical strategies are equally necessary and situationally depended for effective task management.

Comments from interviewees included the following:

- "*The best flights that I've had that have gone, you know, the smoothest always had a solid, you know, plan on the ground ahead of time and a solid briefing on what that plan was before you got to the airplane … I should say in the flights that I've had that haven't gone as well usually correspond with not having that solid plan on the ground … in the moment, now you're relying on that sort of tactical approach, your own kind of skill and, and task prioritization to get you through when, if you would have just talked about it beforehand, you know, you would at least have some mental model"*
- "*I use strategic mostly and employ tactical when necessary. In my opinion, tactical is boots on the ground. Having a plan is great, but sometimes the plan needs to be modified. As soon as you have to modify the plan, now you're in a tactical state. But 90% of the flights, they go forward as planned."*
- "*I think- my opinion is just a process where you just go step, by step, by step, and then repeat it continuously, where you're always looking at the dynamic process. And like you said, the strategic procedures and the resources, and then you go ahead and then there's the tactical aspect where you actually are in the process of accomplishing what was set out to do. And then the last part of that is, of course, redefining it to make sure that what you've done in the first two steps is being accomplished. And then, so when you get to the third step, I believe you go back to the first one and then you accomplish that, and you go back to two to make sure you're still on your tactical aspect of things*."
- "*Tactical. I make, personally, I make a lot of decisions at the strategic level, but in the words of Eisenhower, you know, 'Plans are useless, but planning is essential.' I mean, and it's more just to kind of do a very high-level check.*"
- "*Tactical in that, you know, when things are happening, because it's, I think you mentioned it's dynamic. Things are- weather's rolling in, airports are having problems. Things are happening constantly. You got to roll with it. And it's in the moment, in the present moment. So, although we like to emphasize the strategic, I think I'm personally pretty good and pretty adaptive with the tactical portion."*
- "*If I'm on top of my game it's tactical, you know, but if it's if it's just trying to kill the closest alligator like this, this strategy of I have too many challenges, like I'm behind the airplane and now it's more a strategy … I have to reprioritize immediately and figure out … it just depends on the situation.*"
- "*I'd say really both. You know the planning ahead is huge so I'd say the more strategic you can do the less tactical you have to do and then when it becomes tactical you just prioritize you know the safest thing you know the safety things first.*"
- "*Definitely more planning that goes into it. Because if you can plan for it, then you don't have to do it in a moment, which, that can throw wrenches in the whole plan.*"
- "*I mean, I would say on a normal day, it's more strategic than tactical … And obviously the more it goes into that, you know, the less tactical work you have, you don't have to be worrying about.*"

- "*Like when they start getting saturated, they start holding people to different speeds and things like that at different points on arrivals to help spread the traffic out and ease their workload … the experienced guy is saying, I'm going to program what I just heard…. The guy that's now right in front of him just got the same speed assignment, so I'm willing to bet he's going to get that altitude assignment next. I'm going to go ahead and punch a speed and altitude assignment into the box right now. I just won't execute it until they call me … you're still doing the same task. It's just that the experienced guy is doing it so much earlier when it's not going to be a problem. And the inexperienced guy is reacting."*

6.6. Pilot Perspectives on Task Management Training

Training on task management may be a potential mitigator for task management deficiencies and vulnerabilities. Interviewees were asked about whether they received training on task management and probed for their thoughts on task management training. Forty-one interviewees felt they had received some form of training on task management. Twenty felt that they had received no training on task management. Several interviewees viewed training on CRM, simulator training, and line oriented evaluations as training on task management. These different viewpoints on what constituted training on task management affected their perceived effectiveness of that training. The distinct types of training interviewees discussed are described below.

Classroom-Based Training

Classroom-based training can be an opportunity to integrate theoretical knowledge with practical exercises outside of the flight deck. Interviewees described classroom-based training of task management primarily in the form of running through scenarios verbally with others, reviewing incidents and accidents and discussing them from multiple perspectives, and practicing chair flying with feedback. Lectures on the theory and underlying framework behind crew resource management practices, standard operating procedures, policies, and other related topics was another form of training described as relevant to task management.

Effectiveness:

The degree to which interviewees felt classroom-based training was effective varied significantly. Six interviewees felt that it was not effective or less effective for training task management. Several interviewees felt that classroom-based training has its place and can be useful with the right types of interactions and the right group of people. They believed that there is some information that must first be received in a classroom-type situation. Eight interviewees felt that reviewing incidents and accidents, chair flying scenarios, and having interactive and engaging discussion about scenarios where pilots took the correct action is helpful for building some of the knowledge that can supplement experience. However, they noted that the interactions must be engaging, conducted in such a way that the take-aways will stick, and the pilots more likely to recall that information in the future.

Comments from interviewees included the following:

- *"I think the classroom has its place in starting to develop task management."*
- "*The classroom … can be* [effective]*… we'll have one day of classroom training and in that they'll bring in a group of flight attendants and we'll kind of run through some scenarios there that I think that is effective because you're simulating… everybody involved we've got dispatch we've got the flight attendants we've got you know a medical crew if we need that or that sort of thing so that kind of thing is I think is good.*"
- *"Pilots and cabin crew, we occupy different sections of the airplane, but it's not that we are more important or less important. It's like, it's a team. And if one of the most important things is to be everyone in the team. So, the cabin crew participate in most of the courses where we have as a current, and we do things together. So, we discuss scenarios together, and it's very interesting to*

see the cabin crew point of view and the captain point of view and the first officer point of view. And this might be a good way to reduce the gap in task management training."

- *"In the classroom I don't think you get the same sense of urgency."*
- *"The least effective* [for training task management] *would probably be a classroom."*
- *"You don't get somebody in the classroom say well I had a problem with that one day and it did this."*
- *"If you're in the classroom and you're just reading and not actively making people participate… I think* [that] *will cause a typical pilot to start to daydream and get away with not listening."*
- *"We spend all of our working time in a phone booth with another person at 400, 500 miles an hour. And that's where our comfort level is. That's where our brains are engaged… not the classroom."*
- *"The classroom environment it's okay… as they move on to the next subject and the next subject and now the complexities of all this other stuff… that thing that they learned this morning is out of their mind."*
- *"The theory is great, but it's the practical steps that are going to help people as far as task management."*
- *"It comes down to the realism and potentially the- the verification of a procedure versus just philosophy of a procedure, how- how it will work. So, I need the validation of the process versus the philosophy of a process."*
- *"You can stay in a classroom and listen to an instructor, a very experienced instructor, for hours. But if you don't visualize the problem, I don't know if it's going to help you or not."*
- *"In terms of task management, I would say both simulator and classroom time is valuable. The CRM and task management training in that guided discussion class presentation while you're watching videos… that helps drive in the concept of how your task managements can have some severe consequences."*
- *"If there's classroom stuff, we talk about task management and it's, it's effective because you're zero knots and there's nothing going on. Your brain can absorb all that."*
- *"Going through accidents and incidents investigations related to task management… you think a lot of people died. For you that's really important because it's not something that someone is telling you on theoretical basis, it's something that happened and people died. This doesn't mean that you will not make the same mistake. But probably you will not… that mistake you're specifically not going do because in your brain, you will think ah I saw this before… maybe this will trigger you to do the right thing."*

Computer Based Training

Computer-based training (CBT) refers to the use of computer technology to deliver educational content and training programs. This method leverages multimedia elements such as text, graphics, audio, video, and interactive components to enhance learning and skill development. CBT can be interactive depending on the effort put into developing the training, self-paced, ensure consistency in the form of instruction, and be iterative based on performance. Thirteen interviewees directly referenced CBT.

Effectiveness

All respondents felt that CBT would not be effective for training task management. It is important to note that none of the interviewees felt that they had received task management training through CBT. Their perspective on its potential effectiveness was reflecting on if they were to receive task management training through CBT. Two interviewees noted that it can be useful for systems training and memorization activities (e.g., reviewing systems, checklists, Standard Operation Procedures). Another interviewee noted that it can be helpful given that it allows individuals to go at their own pace. As a method for building knowledge needed for performing tasks, CBT has its place.

Comments from interviewees included:

- *"CBT, computer-based training, is fantastic for systems training. It's fantastic for specific tasks, like de-icing, for example… It's great for security training. And I love the training from that perspective... I've never seen anything effective come out of it with regard to task management."*
- *"We had some pretty good computer-based training because it would go over the same thing maybe three different ways … you'd have to respond to it and then you'd be immediately tested on it… it was pretty good for recurrency and keeping the systems and things in your head, keeping the rules in your head that you need to remember."*
- *"You can look at PowerPoints all day and you can read as many books as possible. But until you correlate with your hands… that's how you're going to build deep experience"*
- *"I find completely ineffective computer-based training. They're boring, and I just don't want to sit through them."*
- *"You're clicking through slides or reading… the least effective is computer-based training."*

Simulator Training

Simulator training involves the use of flight simulators to train pilots. These simulators recreate the flight deck environment and varying flight conditions providing opportunities to practice and hone skills in a controlled, risk-free setting. Simulators can range significantly in fidelity; interviewees referred to full flight simulators in reference to the benefits in training task management. All interviewees were asked about simulator training, and the extent to which the simulator reflects reality was a key consideration for interviewees on its usefulness in training task management. The assumption among interviewees appeared to be that task management can only truly be trained in the context of performing tasks, and this performance of tasks must be done in a realistic environment. The strategies that the interviewees said they leverage for managing tasks effectively were developed and cemented over time, with practice. Practice can occur in lower fidelity environments; however, there was a prevailing perspective among the pilots that practice of task management and task management strategies will be the most effective in the most realistic environments.

Effectiveness:

Simulator training was perceived as extremely effective for task management. Because they believe that simulator training has the potential to be effective, several interviewees voiced concerns regarding the current state of simulator training. They believed that currently simulator training falls short of its potential. There is not enough simulator training to effectively train task management, that simulator training is too rote to effectively train task management, and that simulator training (as implemented) is not realistic enough to train task management. In terms of realism, one interviewee noted that trainers may leverage the position freeze or flight freeze option too frequently. Because this is not how the aircraft operates, the thought is that this can result in challenges for some individuals in managing their tasks when they go to the line. This interviewee did note that the use of position freeze and flight freeze seems to have declined and is less problematic than it used to be. Another concern regarding realism was in terms of task loading. Simulators can offer an opportunity to both explore and train responses to task loading. Some interviewees had experienced this in the past, too varying degrees of success. There was some concern among interviewees about how training responses to task loading might occur, though they saw a need for it in the context of task management. Another concern of realism for task management was regarding time. One interviewee felt that time in the simulator is different from time in the aircraft, and there can be a negative transfer potentially from the simulator to the aircraft in terms of recognizing how much time is actually available to address an abnormal situation.

Sample comments from interviewees:

- *"The stuff that is effective is obviously the full motion simulator, going through different scenarios."*

- *"I think our training has become less effective over the years because they've shortened the simulators. They're trying to squeeze more in, we only have so many simulators and we're hiring so many pilots that need training."*
- *"They really figure out ways over the years of doing things … to get you distracted from your situational awareness, you know? And so, and then it's good in training because it makes you realize how easily that can happen… you sit there and go, oh, this would have happened to me in real life. I might have pulled out in front of an airplane."*
- *"As far as task management training… it's really simulated training… you need to have hands-on experience. And the easy way to get that is a simulator."*
- *"Having trained … in the simulator, I think, definitely helps prepare you, you know, to deal with that situation, but you always have that startle factor, you know, yeah, that warning goes off, it's like oh what do we got here… once you get over the startle factor, and you know, don't get tunnel vision, and keep your situational awareness, I mean, I think that's the key to not get locked in on one thing."*
- *"And so obviously the simulator is priceless… but, but there's times where I've been in the simulator, and something has happened in a strange way… I wonder if that's a simulator issue. I wonder if that's a six-ism. And so, there's still no replacement for being in the aircraft for these experiences, but certainly the simulator is the best place that I can think of… you can talk about it in the classroom all day long and it can only sink in so much."*
- Pilot states that motionless sims actually helped pilots prepare for full-motion simulators: *"Actually, it was wired in where the MCDUs worked, and you could get PFD and all the ND information. It just didn't move… we incorporated all of what we learned with… and then it prepped you for full motion simulator."*
- *"There is motion, but it's different than the airplane, it makes the simulator harder because whenever I've had problems in the airplane setting, it's much easier because you do have a little… sensing seat of the pants or some action you're picking up on that slows everything down. Where in the sim, things happen where it's all visual… which I think is good because that way, you learn to fall back on that and go, OK, I'm going to trust what I see, and it takes a little more processing power in your brain to do it because you don't have any other cues."*
- *"In the simulator, you're blocked into a time to be able to use the simulator, and you've got a set of tasks that you have to accomplish in that amount of time… you're given the time to run through the issue, but there's kind of an overlying sense of getting through this task and learning what we can, what we need to, so that we can move on to the next task. In the aircraft, when you actually have an issue, when you have a problem, most of the time tend to have more time than you do in the simulator. So, the challenge is to slow down a little bit and take your time, take the time that you need, and make sure that you've completed all of the requirements for getting the aircraft safely down."*
- *"Two full simulators of just normal task management within that aircraft… normal flying and utilizing the avionics and building normal approaches and flying normal approaches and all that kind of stuff, instead of just starting off right into handling multiple emergencies."*
- *"The simulator training environment … is a little bit artificial because if I'm in the sim we all know what's going to happen here. We've got three hours to be in the sim. We're going to be in it for an hour and a half. Then we're going to take a break. We're going to go back into it for another hour and a half. And in that time, we've got to do, like, seven different emergency scenarios… it's even more rushed in the sim than what it would be in the actual aircraft… I end up having to speed up more than what I would even do in the aircraft… whereas in the aircraft it's you know you can take your time."*
- *"We'll call it the simulator mindset where it's, I guarantee you, you give any pilot a low speed reject and that's not going to be a problem for them. They'll just be like, oh, I got to stop… maybe I guess we don't have enough surprise in our training."*

- *"When you go into the sim you learn procedures and knowledge but knowing you're not going to die plays a big factor into things… you're really not going to hurt anything… you always have that in the back of your mind."*
- *"I like the simulator training, a lot of people don't… I always enjoyed it because it's the only time you get to do something different in the plane, you know, and so you run through a bunch of different scenarios and how you handle those is exactly the way you should do it in real life."*

Virtual Reality (VR)

Virtual Reality (VR) training uses immersive, computer-generated environments to simulate real-world scenarios and operations. VR is not yet common; the majority of interviewees (45) stated that they have not used it for training.

Effectiveness

Several interviewees stated that they thought it could be effective as an early step in training, though maybe not specifically training of task management. Interviewees commented that VR could provide visuals of the flight deck environment in a potentially realistic, yet still infrastructure light modality. The visuals and ability to interact with the flight deck could help pilots practice flows and order of tasks and become familiar with where to source and find information. Other interviewees felt it may be too similar to CBT and therefore not engaging enough to effectively train task management. Finally, one interviewee mentioned that there was exploration of VR as a training tool, but there potential downsides with participants developing cybersickness.

Sample comments from pilots included:

- *"In a VR situation, if you had goggles on that simulated the flight deck and you were actually able to see the manipulation of button switches, control surfaces, things like that, I think that would be effective."*
- *"If we had more simulator time and training, I think that that would definitely be beneficial, but it's expensive. If maybe they switch to supplementing that with some type of virtual reality, because I think when you're training for task management… you're doing mental exercises. Maybe with virtual reality, you could implement some startle factor or realism, so it feels a little bit more real. And so, your decision making is more in line with what you would do in the actual situation. I could see benefits to that."*
- *"This is where something like VR or certainly flight sim can assist you a lot because if you spend a lot of time in that environment, you can solve a lot of those initial problems that you have when you go in the sim by ultimately just knowing where to source and find the information you need."*
- *"I feel like I may get the same feeling of disinterest in virtual reality because the pressure is not there."*
- *"I can definitely see the benefits of it, especially. You know when you're, during initial training, being able to do all the virtual, virtual reality stuff in terms of learning your flows and procedures and everything else. I think that would be, you know, an incredibly powerful educational tool."*
- *"Our director of training said that we are moving towards that… bought a whole bunch of goggles. I figure that it's going to be some time before we can actually come up with a way to mitigate the downsides… you can only keep the person on the goggles for maybe 45 minutes at a time, and then they need to get a 15, 20 minute break from it … because… the eyesight, headaches, dizziness and vomiting."*

7. DISCUSSION

Causal and contributing factors related to interruptions, disruptions, distractions, communication, time management, pressure, taskload, task saturation, task allocation, fatigue, stress, individual differences,

international ATC, system complexity, and operational complexity were identified based on interviews with sixty-one individuals. Throughout the findings, a recurrent theme was deficiencies and vulnerabilities resulting from high taskload during complex operations (e.g., weather, night operations, high traffic) and critical phases of flight. Another theme was the interconnected and overlapping presence of causal and contributing factors to task management deficiencies and vulnerabilities. Across the insights elicited from the interviewees, it was rare for only a single factor to be discussed or described; usually multiple factors may have been relevant. Future work is needed to understand the relative importance or contribution of multiple factors to task management deficiencies and vulnerabilities in order to optimize mitigations.

Six categories of mitigations were identified that included communication mitigations, policies and procedures, prioritization strategies, metacognitive strategies, strategic and tactical strategies to organizing tasks, and training. Many pilots also highlighted the critical role of experience in developing the ability to anticipate and mitigate potential issues proactively. Pilots perceived most mitigations as effective in addressing factors like individual differences, task allocation, and communication. However, there may be an opportunity to enhance mitigations to further address these factors as well as interruptions, disruptions, distractions, fatigue, stress, time management, pressure, international ATC, system complexity, and operational complexity.

Shared Mental Models as a Mitigation for Task Management Deficiencies and Vulnerabilities

One key theme to emerge was related to the importance of establishing robust shared mental models as a mitigator for task management deficiencies and vulnerabilities. Because of the interconnected and overlapping presence of causal and contributing factors to task management deficiencies and vulnerabilities, establishing a robust shared mental model has potential to mitigate task management deficiencies and vulnerabilities across several factors, including perception of time, recovery from disruptions and distractions, task saturation resulting from improper workload distribution, problems resulting from personality differences, inexperience, and complacency. Shared mental models between ATC would also help to alleviate task loading and unexpected domestic/international airspace operations.

Shared mental models enable pilots to anticipate each other's actions, communicate effectively, and make coordinated decisions, particularly in high-stress or emergency situations. When both the pilot and co-pilot have a synchronized mental model, it reduces the likelihood of miscommunication and errors, as each can quickly interpret and respond to the other's cues and directives. This alignment is critical for managing complex tasks, as it allows for efficient division of labor and enhances situation awareness.

From the interviews, robust shared mental models provide a mutual understanding and similar expectations between pilots regarding the current state of the aircraft, upcoming tasks, and potential challenges. Robust shared mental models are more easily established when crew members use a standard language, have common experiences (in training, in the aircraft, at the operator), from similar initial assumptions about the other crew member, communicate effectively with the appropriate level of detail, establish common goals, have complimentary personalities, similar backgrounds and/or they establish common ground in the face of different backgrounds. As a result, rapport may develop between the pilots which strengthens the shared mental model, however rapport is not a prerequisite.

While a pilot may be able form a good initial individual-level mental model, the robustness of the shared mental model is reliant on continual and effective communication, but also the ability of the pilot to change one’s expectations when reality checks occur. Effective communication needs to be consistent throughout the flight. Human factor vulnerabilities, such as stress, workload, task saturation, fatigue, and startle and surprise may lead to situations where communication is reduced. A robust shared mental model may still be proficient in helping them achieve effective task management even under conditions where both pilots are task saturated. A robust shared mental model can operate temporarily without communication, but further communication vulnerabilities will quickly degrade the shared mental model.

There are two shared mental model vulnerabilities that may affect task management: mental model misalignment between pilots, or a shared mental model that is incorrect. Mental model misalignment between pilots happens when one pilot's individual-level strategic mental model of the flight differs from another crew member. This can happen due to human factor vulnerabilities (e.g., stress, workload, task saturation, fatigue, and startle and surprise) or dynamic changes to the flight. Misalignment may also happen if one pilot does not communicate, for example, "*where the FO is very inexperienced, and the captain is very experienced, there may be a reluctance to speak up and correct a deficiency*." Inexperienced pilots may also struggle with assertiveness, leading to hesitations in voicing concerns or suggestions, which can result in information being overlooked or delayed (Helmreich & Foushee, 2010). Moreover, they may have difficulty interpreting non-verbal cues or subtle hints from their more experienced counterparts, leading to less robust shared mental models. Effective communication between pilots can re-align the shared mental model, and potentially reduce the effect from the contributing factor.

In certain situations, a trap may occur in which both pilots form an incorrect shared mental model. These situations could arise from erroneous sensor information, misperception of the environment, misunderstanding or misinterpretation of some information. The pilots will not be aware that shared mental model is incorrect. Until corrected, that shared mental model may continuously provide the pilots with a false expectation. No other mitigation or metacognitive strategy (e.g., ANCS, prioritization strategies) will be able to correct a wrong shared mental model. One pilot shared an example, "*So, there was a similar call sign human factors issue. We had a [airline] flight with a similar call sign, get ready to depart runway two, two. And, we had company on about a three-mile final runway 12 right, our runway. … But what I heard was our call sign … I asked my FO. I said, was that for us? … And he goes, yes. And I said, okay, let's go. Came around the corner, pushed the power up … initiated the takeoff, and that clearance wasn't for us. It was for company on runway 22, and he was rolling also … He aborted the takeoff, stopped well before the intersection of the two runways. We rotated before the intersection of the runways as well. But that could have been a Tenerife."* Both pilots misunderstood the callsign which led to an incorrect mental model. Neither pilot was aware that the shared mental model was incorrect.

In terms of mitigations, training programs that emphasize the development and reinforcement of shared mental models may mitigate task management deficiencies and vulnerabilities. Additionally, twelve pilots discussed how important briefings are to establishing a robust shared mental model and that giving an effective briefing is a skill and not all pilots may deliver high-quality briefings. Research exploring how to focus and train the skill of briefings to support robust mental models, for example, handling interruptions and adapting the briefing to the skills, knowledge and experience of the other pilot may further mitigate task management deficiencies and vulnerabilities.

Training as a Mitigation for Task Management Deficiencies and Vulnerabilities

In regard to training, there was a prevailing perspective among the pilots interviewed that realistic environments (e.g., full flight simulator or on the line) are the most effective in building pilot proficiency in task management. There was also a prevailing assumption that to become deeply proficient at task management, training will not suffice, even in a full motion simulator. Experience on the line is needed. While simulators are important for providing experiences that pilots infrequently encounter on the line, operational experience was considered more effective for learning task management because it is in the real-world; pilots experience real time pressure and real-world factors (such as ATC, flight attendants, and passengers) that contribute to complicating task management. In addition, pilots associate the ability to effectively manage tasks, especially when presented with abnormal situations, with greater knowledge and skill. Experience builds knowledge and skill by encompassing both the practical application of learned concepts and the personal insights gained from conducting flights.

One proposed mitigation to accelerate what can be gained through experience on the line was knowledge gained through information exchange. Information is less optimal than training in realistic environments but may provide an alternative supplementary mitigation. Safety data can provide insight into training topics, and several pilots commented that walking through accidents and incidents, having robust dialogue about these situations, and especially talking to other pilots who experienced abnormal events gave them knowledge on how they might handle the same event, what went wrong, and what went right. Anecdotally, this type of learning does appear to make a difference. However, research should evaluate the extent to which this knowledge transfers; do pilots do "recall" or "remember" in new or novel situations how to respond based on this type of learning?

There may be other, similar opportunities to build the fundamentals of task management initially outside of the flight deck, prior to gaining experience on the line, despite the prevailing assumption. For example, it is unclear from the interviews whether there is an ideal distribution of leveraging strategic versus tactical strategies for task management. The assumption would be that there is an ideal distribution that is evenly spread across both; prior work would suggest that an equal distribution is important. However, based on the interviews, training seems to emphasize tactical strategies to managing tasks and that this training is rigid. Simulator training sessions have set times and specific goals. While goals can address both strategic and tactical task management, rigid tactical decision making receives a lot of emphasis. The ability to exercise strategic thinking may be limited as a result. In addition, the ability to dynamically manage tasks when things don't go according to plan is the ultimate goal of proficiency in task management, but with the majority of the simulator session be pre-planned, developing the ability to dynamically manage tasks may be restricted. Research should explore opportunities to train dynamic task management and investigate further the need for training of strategic strategies to task management.

8. CONCLUSIONS & NEXT STEPS

This report summarizes interviews conducted with 55 Part 121 commercial transport pilots and six other individuals with experience of Part 121 training and operations on potential causal and contributing factors to flight deck task management deficiencies and vulnerabilities as well as current mitigations and their effectiveness. This work identified current casual and contributing factors and six categories of mitigations. Three major take-aways are that (1) mitigations do not fully account for the impact of complex operational environments introducing high taskload, fatigue, and stress on task management, (2) gaps remain in effectively applying task management strategies, especially in high workload conditions, and (3) methods to effectively train task management are lacking.

There are many recommendations which could be made regarding these take-aways and for each human factor and mitigation identified. However, based on the interviews, three recommendations would help address the gaps observed. The first is exploring training that can increase the effectiveness of existing mitigations. Enhancing existing mitigations has potential for reducing task management deficiencies and errors by strengthening the effects of those mitigations. For example, focused training on developing metacognitive skills that can help pilots more effectively apply task management strategies. This includes developing skills related to perception of time to ensure pilots can recognize situations where the time they personally need to execute tasks may not align with time available (or does align with the time available) and are able to recognize when the time to execute tasks may differ between crew members (e.g., captain may be able to perform tasks faster than FO). Training that focuses on the skills of briefing, such as handling interruptions to briefings and adapting the briefing to the skills, knowledge and experience of the other pilot, may help strengthen briefings as a mitigation. Additionally, alternatives to simulator training that can supplement knowledge and experiences, and train prioritization strategies should be explored as a way to train task management proficiency. The second recommendation would be to explore potential mitigations for stress and fatigue. Current mitigations are minimal; future work should examine training and procedural mitigations to address the effects of stress and fatigue on task management. Finally, many of the factors

identified are interconnected and frequently co-occur, making it challenging to assess which are the most pertinent as causal and contributing factors to task management. Recommendations here are based on the perceptions of pilots, and that is a major limitation of this work. Pilot perceptions can be biased. Future work may benefit from validating the relative importance of the multiple, co-occurring human factors identified in order to optimize enhancements to mitigations and the exploration of new mitigations.

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APPENDIX A – LITERATURE REVIEW

HON_TaskManage
ment_LiteratureRevi

APPENDIX B – INTERVIEW QUESTIONS

Participant ID_____ **Date _____**

Total Flight Hours: _____
Type Ratings: _____
Certificates and Ratings: _____
Age: _____

Gender: Male Female Prefer not to say

Which aircraft have you flown the most in terms of total flight hours? (Please list specific type)
_____
At your operator, which aircraft are you qualified and current to fly? (Please list specific type)
_____
At your operator, which aircraft have you flown most recently? (Please list specific type)
_____
Outside of flights for a Part 121 or 135 operator, what other aircraft and operations do you fly?
_____

Date of your last flight in an air transport aircraft: _____
Type of air transport aircraft on date of last flight: _____

What management position (if any) do you currently hold at your operator?
_____

What management positions in Part 121/135 operations (if any) have you held with your current or past employer?
_____

I am an FAA approved instructor for an aircraft at my operator? Yes No

I am a check airman? Yes No

I am currently a pilot for a (select all that apply):

- **Part 121 operator**
- **Part 135 operator**
- **Part 91K operator**

I am a:

- **Captain**
- **First officer**
- **N/A**

at my current employer.
Participant ID_____ **Date _____**

1. How do you define task management?

   Where did you learn about task management?

[ask the participant to explain further]
For the rest of the interview, let's use this definition of Task Management:
Task management is a dynamic process that involves both strategic and tactical organization of pilot tasks over the course of a flight. Strategic activities involve proactive planning, task prioritization, task allocation, task resource management, timing of tasks, and anticipating and assessing the flight situation. Tactical activities are to monitor and respond to real-time changes in the flight situation and include monitoring task performance, reprioritization, reallocation, making decisions, and managing emergent events and disruptions. The primary objective of task management is to support the "aviate" task while balancing other operational objectives.

Do you have any questions about this definition?

2. Based on recent experience, provide an example of effective flight deck task management.
What strategies helped you effectively manage time?
What strategies helped you manage workload?

3. Based on recent experience, provide an example of ineffective flight deck task management.
[ask follow-up questions to ensure understand why they believe example was ineffective]

4. It's recommended that air carriers' clearly address the roles and responsibilities of the PF and PM related to managing energy and flightpath in all phases of flight. In the study you just did, the PM only acted when asked. How do you feel like this affected managing your energy and flightpath?

5. In the study, how did the ATC instructions that you received throughout the scenarios affect your ability to manage your tasks?

6. What policies and procedures does your operator have in-place that help with effective flight deck task management?

What policies and procedures does your operator have in-place that negatively affect flight deck task management?

[Ask follow-up question about the effects on tactical flight deck tasks such as monitoring and respond to real-time changes in the flight situation]

[Ask follow-up question about the effects on strategic flight deck tasks, such as take-off and approach planning]

4. Do any of the procedures you've encountered require you to do multiple tasks concurrently?

[Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

5. At your operator, are there existing policies and procedures that disrupt the logical flow or sequence of tasks executed during a line operation?

[Ask follow-up question about the effects on tactical flight deck tasks such as monitoring and respond to real-time changes in the flight situation]

[Ask follow-up question about the effects on strategic flight deck tasks, such as take-off and approach planning]

[Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

6. Task management is a dynamic process that involves both strategic and tactical organization of pilot tasks over the course of a flight. The primary objective of task management is to support the "aviate" task while balancing other operational objectives. How does this relate to the task management strategies you use?

   [NOTE: do not provide the definitions tactical and strategic examples to avoid biasing their answer.]

   [Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

7. *[Question may be removed due to time constraints – the goal of this question is to get at dynamic prioritization, but this may be resolved by earlier questions regarding strategies].* Pretend you are experiencing routine task saturation while flying a visual approach in busy airspace with deteriorating visibility; then suddenly you encounter an emergency. How would you prioritize tasks in this situation?

   [Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

8. Is your response based on information learned during training provided by an operator or through operational experience?

   [Ask the participant to explain further to ensure interviewer understanding]

9. Did you learn task management strategies during training provided by an operator or through operational experience?

   [Ask the participant to explain further to ensure interviewer understanding]

10. Please explain how you plan, manage, and execute tasks with other flight deck crewmembers and non-flight deck crewmembers during a line operation.
    [Ask the participant to explain further to ensure interviewer understanding]

11. Did you learn these strategies during training provided by an operator or through operational experience?
    [Ask the participant to explain further to ensure interviewer understanding]

12. How do the strategies you learned through training compare to your experiences working on the line?
[Ask the participant to explain further to ensure interviewer understanding]

13. Do you prefer to receive training on flight deck task management during ground, simulator, operating experience, or line operations?
[Ask follow-up question regarding preferences to ensure understanding of why]

14. Which types of training are most effective for flight deck task management?
[Ask follow-up question regarding why to ensure understanding]

Which types of training are least effective for flight deck task management?

[Ask follow-up question regarding why to ensure understanding]

15. Do you currently use VR, AR, or MR during operator training?
If yes, how effective is the technology?

If no, how effective do you feel like it could be?

[Ask follow-up question regarding why to ensure understanding]

16. What are time management strategies you routinely use while completing flight deck tasks?
[Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

17. When you are task saturated how do you manage time to ensure all flight deck tasks are completed effectively?
[Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

18. During an emergency situation how do you manage time to ensure all flight deck tasks are completed effectively?
[Ask follow-up questions to ensure interviewer understanding of any examples referencing malfunctions or failures, and/or the effect of different perspectives (i.e., role)]

19. Did you learn these strategies during training provided by an operator or through operational experience?
[Ask the participant to explain further to ensure interviewer understanding]

20. Pretend you are flying an aircraft at altitude and workload is low. All of the sudden you experience a cracked windshield. Can you walk through how you would manage time to complete tasks necessary for this situation?
[Ask the participant to explain further to ensure interviewer understanding]

21. Provide an example from recent line operations where your time management strategies did not align with another crewmember?
[Ask the participant to explain further to ensure interviewer understanding]

22. At your operator, do the existing policies and procedures for line operations and training accommodate different time management strategies?
[Ask the participant to explain further to ensure interviewer understanding]

23. If you are working with another pilot who manages time differently, how do you get and stay on the same page with each other?
[Ask the participant to explain further to ensure interviewer understanding]

24. *[Question may be removed due to time constraints, and that the goal of this question to elicit time management strategies during periods of low workload may be resolved with earlier questions regarding time management]* What would you typically do during a period of reduced workload if you anticipate workload might increase within the next 30, 60, and 90 minutes?
[Ask follow-up questions to ensure interviewer understanding of any examples and/or the effect of different perspectives (i.e., role)]

25. How do ATC interventions, or norms, that frequently occur during line operations affect your ability to manage tasks?
[Can provide an example like ATC vectors an aircraft off a published procedure, such as a PBN arrival to a high-density airport, followed by vectors to rejoin the procedure.]

[Ask follow-up questions to ensure interviewer understanding of how ATC interventions may make task management difficult]

[Ask follow-up questions to ensure interviewer understanding of where this may be happening in the National Airspace System

26. How do you use CRM to support effective task management during normal operations?
Does CRM support effective task management?

27. How do you use task management during a line operation for the purpose of threat and error management (TEM)?
[Ask the participant to explain further to ensure interviewer understanding]

28. Any comments, questions, or anything you would like to add?

29. How do you currently train task management?
[Ask follow-up questions of the participant around training of:

- *Strategies (prioritization, time management)*
- *Task shedding*
- *Task switching*
- *Task saturation*
- *Time management*

Follow-ups to ensure interviewer understanding]

30. What gaps do you feel exist in current task management training?

How do feel these gaps could be addressed?
[Ask follow-up questions of the participant to explain further about why they feel these gaps exist and ensure interviewer understanding]

31. What do you find most challenging about task management to train?

What makes it challenging?

[Ask follow-up questions of the participant to explain further]

32. Have you ever seen pilots employ effective task management strategies that are not taught in training?

[Ask the participant to explain further to ensure interviewer understanding]

Additional or Alternative Questions for Other Training Personnel:

The following questions may be added in addition to the above questions for flight training personnel. Depending on the role of the individual, pilot-specific questions from above will be removed. Questions such as "How do you define task management?" that are still applicable to non-pilot roles will still be asked. The questions below may be expanded/modified depending on who is recruited to be interviewed from this category.

Additional/Alternative Demographics Questions

What is your current role?

Please describe the responsibilities of this role

How long have you been in that role?

What previous roles have you held?

Additional/Alternative Interview Questions

33. What are your responsibilities in regard to pilot training?

34. What deficiencies or vulnerabilities do you see with task management in today's pilots?

35. How is task management currently addressed in training?

36. How can (or how does) training of task management address these challenges? Are there any gaps that you feel need to be addressed that are not?

APPENDIX C – LIST OF EXTRACTED CODES

The following are the codes that were created in MAXQDA to help extract relevant excerpts from pilot interview transcripts:

Research Questions
- Deficiencies & vulnerabilities
- Mitigations to dom/int for TM
- Effectiveness of mitigations

Task Management Concepts
- **TM strategies**
  - Checklist
  - Green, yellow, red
  - Slow down situation
  - Personalized Reminders
  - Proactive Pilot Behavior
  - Task allocation
  - ABCD model
- **Operational Experience**

Training Practices
- TM theory (Volant, swiss cheese)
- Quarterly based training
- Check Rides
- VR
- Simulation
- Computer-based training
- Classroom training

ATC
- **Pilot behavior with ATC**
  - Helpful
- **ATC problems/concerns**
  - Landing Disruption
  - Mental model mismatch
  - Domestic vs. International ATC
- **Non-ATC disruptions**

CRM
- Briefings

Shared Mental Models
- Mismatch between Pilots and ATC
- Mismatch between Pilots

Prioritization
- Perceived Severity
- ANC

Psychological Effects
- Fatigue
- Stress
- Startle and surprise
- Social Pressure

- Moral dilemma

Novel Insights

- Play as training
- Skill Degradation
- Inexperience
- Mistakes, Lapses, Omissions
- Personal Reminder
- Scheduling Policies
- Geographic unfamiliarity
- Personality Differences
- Cultural Expectations
- Co-pilot communication
- Mental model mismatch between...
- Social Pressure
- Moral dilemma
- Inefficient time mgt strategies
- Inefficient TM strategies
- Disruptions, interruptions, task loading

Aircraft System

- System Task Management Considerations
- System Failure Example