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This report documents the data and findings of a research study conducted to (1) collect an inventory of flightpath management (FPM) cognitive skills and examples of flightpath management knowledge for Part 121 operations and (2) investigate how susceptible FPM cognitive skills and knowledge are to degradation. A human-in-the-loop (HITL) simulation study evaluated how FPM cognitive skills and knowledge may degrade using a between-subjects design with B737 and A320 type-rated pilots. Degradation resulting from time away from flying was assessed by comparing 24 participants belonging to one of three groups: (1) individuals who meet requirements as defined in 14 CFR 121.439 pilot qualification for recent experience (n = 8), (2) individuals who used to qualify for recent experience but whose last flight in one of those aircraft was 6-12 months in the past (n = 8), or (3) individuals who used to qualify for recent experience but whose last flight in one of those aircraft was 12 – 24 months in the past (n = 8). The twenty-four participants completed seven scenarios in their aircraft type with twelve participants in the A320 and twelve participants in the B737. Study findings suggest that declarative knowledge of the functions and interactions of the Flight Management System (FMS) and autoflight systems, including the flight director, autopilot, autothrottles, and flight mode annunciations are more susceptible to degradation than other types of knowledge. The cognitive skills of collection, integration, and estimation appear more susceptible to degradation than prediction, planning, and communication. In addition, pilots who had been away from flying for 12-24 months appeared to execute cognitive skills of information collection, integration, and estimation at a slightly slower frequency. Findings also suggest degradation in skill and decay in knowledge was not strictly due to time away from flying but may also result from other factors. Potential mitigations include continual reinforcement and training in self-assessment.

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ACRONYMS

AC	Advisory Circular
ACARS	Aircraft Communications Address and Reporting System
ACS	Airman Certification Standards
ACT ARC	Air Carrier Training Aviation Rulemaking Committee
ADS-B	Automatic Dependence Surveillance – Broadcast
AFM	Aircraft Flight Manual
AGL	Above Ground Level
AP	Autopilot
APPR	Approach Mode
ARTCC	Air Route Traffic Control Center
A/T	Autothrottle/autothrust
ATIS	Automatic Terminal Information Service
ATP	Airline Transport Pilot
ASRS	Aviation Safety Reporting System
CFI	Certificated Flight Instructor
CFII	Certificated Flight Instructor Instrument
CFR	Code of Federal Regulations
CPDLC	Controller-Pilot Data Link Communications
CDU	Control Display Unit
CMD	Command Mode
CWS	Control Wheel Steering
ECAM	Electronic Centralized Aircraft Monitor
EFB	Electronic Flight Bag
EFC	Expect Further Clearance
EGPWS	Enhanced Ground Proximity Warning System
EICAS	Engine Indicating and Crew-Alerting System
FAA	Federal Aviation Administration
FD or F/D	Flight Director
FMA	Flight Mode Annunciator
FMS	Flight Management System
FMC	Flight Management Computer
FO	First Officer
FPM	Flightpath Management
FT	Feet
FTD	Flight Training Device
HITL	Human-in-the-loop
HUD	Head-up Display
IA	Information Automation
IAS	Indicated Airspeed

ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRB	Institutional Review Board
KLAX	Los Angeles International Airport
KPHX	Phoenix Sky Harbor International Airport
KSFO	San Francisco International Airport
KTS	Knots
LNAV	Lateral Navigation
MEL	Minimum Equipment List
METAR	Aviation Routine Weather Report
MCP	Mode Control Panel
MM	Moving Map
MSL	Mean Sea Level
ND	Navigation Display
NEXTGEN	Next Generation Air Transportation System
NOTAM	Notice to Air Missions
OPD	Optimized Profile Descent
PAPI	Precision Approach Path Indicator
PFD	Primary Flight Display
PF	Pilot Flying
PM	Pilot Monitoring
POH	Pilot's Operating Handbook
RNAV	Area Navigation
RTLX	Raw TLX
RWY	Runway
SID	Standard Instrument Departure
SME	Subject Matter Expert
SOCAL	Southern California Terminal Radar Approach Control Facility
STAR	Standard Arrival Route
TCAS	Traffic Alert and Collision Avoidance System
TLX	NASA Task Load Index
TOD	Top-of-descent
TRACON	Terminal Radar Approach Control
VNAV	Vertical Navigation

EXECUTIVE SUMMARY

Flying is cognitively complex, and degradation of cognitive skills and knowledge has potential to affect flight operations. Research across several domains has shown cognitive skills and the knowledge needed for their execution can deteriorate for a variety of reasons including changes in routine, lack of continual training, aging, and time away from the task environment (Arthur et al., 1998; Cant et al., 2021; Park et al., 2022; Woodman et al., 2021). Specific explorations of cognitive skills in aviation are relatively new and tend to focus on general aviation. Within this context, some early research has suggested that the introduction of automated systems to the flight deck may contribute to the degradation of cognitive skills needed for manual flight planning calculations (Volz & Dorneich, 2020). Open questions remain about cognitive skill and knowledge degradation in aviation, and the potential effects on cognitively complex activities like flightpath management in transport aircraft during Title 14 Code of Federal Regulations (CFR 14) Part 121 air carrier flight operations. For example, it is unclear which cognitive skills for flightpath management may be most susceptible to decay and degradation. It is also unclear whether the reasons or causes for skill degradation in other domains apply to degradation of cognitive skills and knowledge for flightpath management in transport aircraft during CFR 14 air carrier flight operations.

Flightpath management (FPM) is the planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in flight or on the ground (FAA Advisory Circular (AC) 120-123: Flightpath Management, 2022). To accomplish FPM tasks, pilots may form internal representations, known as mental models, of how they expect the external world (e.g., the aircraft, systems, environment) to behave using multiple cognitive skills concurrently with knowledge to process, store, and analyze information (Hardy & Parasuraman, 1997). A cognitive skill is the ability to retain and combine knowledge about a domain and then be able to apply, generalize, combine, and transfer this knowledge to perform complex intellectual tasks (VanLehn, 1996). For example, Air Traffic Control (ATC) may request an aircraft to reduce speed on an arrival. A pilot may use cognitive skills with knowledge to decide what actions need to be made to execute the request and manage the flightpath and aircraft energy accurately and efficiently. Cognitive skills such as information collection, integration, estimation, prediction, and planning would be used to combine, apply, generalize, and transfer knowledge. Knowledge might include information about the aircraft (e.g., its current state, performance, etc.), knowledge of automated systems, knowledge of procedures and policies, and more. Degradation of these cognitive skills and knowledge could affect pilots' abilities to plan, execute, and assure the aircraft's flightpath.

This research investigates the cognitive skills and knowledge for certain FPM tasks in transport aircraft during 14 CFR Part 121 air carrier flight operations where FPM involves the planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in flight or on the ground (FAA AC 120-123: Flightpath Management, 2022). A goal of this work is to obtain empirical research data to indicate which cognitive skills and knowledge for FPM tasks might be susceptible to decay and degradation, and why. A secondary goal is evaluating potential strategies to help mitigate or manage the possibility of decay and degradation of certain cognitive skills and knowledge. Three research questions (RQ) are posed towards these objectives:

RQ1. Which cognitive skills and knowledge are susceptible to decay and degradation?

RQ2. What are potential reasons cognitive skills and knowledge may be susceptible to decay and degradation?

RQ3. What are potential strategies to help mitigate or manage decay and degradation of cognitive skills and knowledge?

To answer these questions, this work first summarizes an inventory of the cognitive skills and knowledge needed for FPM, and then based on the inventory, a human-in-the-loop (HITL) study was designed and conducted to provide insight into the three posed research questions.

Cognitive Skills Inventory

The inventory was developed using cognitive walkthroughs with subject matter expert pilots current in the Airbus A320 and Boeing 737NG. The inventory links four FPM objectives to a series of cognitive tasks, cognitive skills, and knowledge needed to execute the cognitive tasks. The four FPM objectives are:

1. Form an understanding (mental model) of the plan for the flight and make sure the airplane is prepared appropriately.
2. Ensure joint (flight crew) understanding of the plan for the flight.
3. Assure current position (lateral and vertical) and energy state is correct per plan, including proximate constraints.
4. Assure trajectory (lateral and vertical) and energy trend is correct per plan, including upcoming/future constraints.

The inventory details ten cognitive skills which support 16 cognitive tasks associated with achieving these four FPM objectives. Cognitive skills include collection, assessment, integration, interpretation, estimation, prediction, comparison, planning, communication, and mental construction. The inventory also emphasizes the importance of declarative knowledge (facts), procedural knowledge (how to perform tasks), and abstract or general knowledge, such as schemas or mental representations, which are used to process experiences, organize information, and retrieve information. Examples of knowledge includes knowledge of the functions of the flight management system (FMS), FMS interactions with autoflight modes, knowledge of autoflight systems including flight director (FD), autopilot (AP), autothrottle/autothrust (A/T), and flight mode annunciator (FMA)s, knowledge of standard flight profiles for all phases of flight, local knowledge about the route, area, airplane, airport, and destination, company-specific procedures, and knowledge of heuristics that are applicable to the task and phase of flight, and how and when to apply them.

Human-in-the-Loop Study

Seven operational scenarios simulating a flight from Phoenix to Los Angeles were designed to elicit and assess a subset of the ten identified cognitive skills: information collection, integration, estimation, prediction, planning, and communication. The focus in this study was the degradation resulting from time away from flying, which was assessed by comparing three groups of participants: (1) individuals who meet requirements as defined in 14 CFR 121.439[1] pilot qualification for recent experience, (2) individuals who used to qualify as having recent experience in either an A320 or B737 but whose last flight in one of those aircraft was 6-12 months in the past, or (3) individuals who used to qualify as having recent experience in either an A320 or B737 but whose last flight in one of those aircraft was 12 – 24 months in the past. Twenty-four participants total completed seven scenarios in either an A320 simulator or a B737 simulator. There were eight participants in each of the three groups, with four participants per group for each aircraft type. Data were collected through verbal protocols, video and audio recordings, and simulator performance metrics. Qualitative analysis in the form of verbal analysis was used to assess how cognitive skills and knowledge differed between the three groups of participants, supported by visualizations of flightpath indices. For the second and third group, eleven participants returned five months after the first study for a follow-up to assess the longitudinal effect of time away from flying on skill degradation.

[1] 14 CFR § 121.439 Pilot qualification: Recent experience. See details at https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-121

RQ 1: Cognitive skills and knowledge are susceptible to decay and degradation?

The results from this study suggested that declarative knowledge of the functions and interactions of the Flight Management System (FMS) and autoflight systems, including the FD, AP, A/T, and FMAs are more susceptible to degradation than other types of knowledge, such as declarative knowledge of the basic principles of flight control and engine systems. Knowledge of heuristics also showed the potential to degrade, along with the cognitive skill of estimation to execute heuristics, but the declarative knowledge of standard flight profiles for all phases of flight showed resilience. Local knowledge gained from experience, such as terrain awareness of Phoenix and traffic flow at Los Angeles International Airport (KLAX), did not appear to degrade. Knowledge of company-specific procedures and recall of where to find relevant FPM information on navigational displays (ND), the FMS, primary flight displays (PFD), and engine indication and crew alerting systems (Electronic Centralized Aircraft Monitor (ECAM) / Engine Indicating and Crew-Alerting System (EICAS)) appeared to have degraded for some participants, impacting execution of cognitive skills that rely on knowledge. For example, collecting information from a particular page in the FMS can be impacted by knowledge degradation of where to find that information. Depending on the degree to which knowledge degradation occurs, the cognitive skills of collection, integration, and estimation appear more susceptible to degradation than prediction, planning, and communication. In addition, pilots who had been away from flying for 12-24 months appeared to execute cognitive skills of information collection, integration, and estimation at a slightly slower frequency.

There were some differences in knowledge and cognitive skills that did not appear to be related to time away from flying, and this may suggest degradation can occur as a result of factors other than time away from flying. For example, fifty percent (n = 12) of the participants had challenges with collecting and integrating information to program and verify a hold. These challenges with programming and verifying the hold were not related to group differences. Similarly, there were distinct differences in participant skills of planning and prediction, but these differences did not appear to differ by group and were not related to being away from flying.

RQ 2: What are potential reasons cognitive skills and knowledge may be susceptible decay and degradation?

Across the analyses, there were examples of gaps in knowledge and skills. However, these gaps were not always differentiable by pilot group, meaning the potential degradation in skill and decay in knowledge was not strictly due to time away from flying. Other factors that may contribute to decay and degradation may be changes in technology and procedures and cognitive overload.

Changes in technology and procedures may contribute to and highlight knowledge and skill degradation. While changes in technology or procedures can introduce new skills and knowledge, they can also exercise and test existing skills and knowledge in new ways. Sometimes referred to as transference, exercising the same skill or eliciting the same knowledge in a slightly different way can be a method for assessing the strength of a skill or knowledge recall. Staying consistently with one way of executing tasks can lead to potential degradation, because individuals may reach a point where the skill becomes automatic in that context. This can be good in terms of efficiency, but it can also mean they are no longer exercising the skill and knowledge. New technology which uses the same skill and knowledge may bring to light degradation or decay resulting from automatization.

It is unclear from this study if cognitive overload may contribute to decay and degradation, but cognitive overload can highlight cognitive skills and knowledge degradation as degradation may contribute to cognitive overload. When an individual is overloaded, it can become harder to focus on and retain specific knowledge and skills. While there were no significant differences in reported workload, findings suggested that the 12-24 month pilots were overloaded in the takeoff, climb, arrival, and approach, indicating potential cognitive skill and knowledge degradation.

RQ 3: What are potential strategies to help mitigate or manage decay and degradation of cognitive skills and knowledge?

Based on the results from this study, continual reinforcement was found to be a helpful mitigation to prevent the erosion of both procedural and declarative knowledge and ensure skills remain intact. With the knowledge and memory items that decayed, focused review might suffice to maintain recall ability. With the skills that degraded, practice in context would reinforce mental associations, and keep the skills and knowledge current.

Another potential mitigation is encouraging pilots to regularly evaluate their own skills and knowledge. Self-assessment can help pilots identify areas that need improvement before they become issues. However, based on the verbal protocol employed in this study, results suggest there can be discrepancies between pilot perspective (i.e., what pilots think they did) and reality (i.e., what they actually did). Self-assessment as a skill should be taught to ensure individuals can accurately perceive their performance.

1. INTRODUCTION

In aviation, degradation of cognitive skills and knowledge has potential to affect flight operations. Research across several domains has shown cognitive skills and the knowledge needed for their execution can deteriorate for a variety of reasons including changes in routine, lack of continual training, aging, and time away from the task environment (Arthur et al., 1998; Cant et al., 2021; Park et al., 2022; Woodman et al., 2021). Specific explorations of cognitive skills in aviation are relatively new and tend to focus on general aviation; within this context, some early research has suggested that the introduction of automated systems to the flight deck may contribute to the degradation of cognitive skills needed for inferring the state of the aircraft (Volz & Dorneich, 2020). Open questions remain about cognitive skill and knowledge degradation in aviation, and the potential effects on cognitively complex activities like flightpath management in transport aircraft during 14 CFR Part 121 air carrier flight operations. For example, it is unclear which cognitive skills for flightpath management may be most susceptible to decay and degradation. It is also unclear whether the reasons or causes for skill degradation in other domains apply to degradation of cognitive skills and knowledge for flightpath management in transport aircraft during CFR 14 air carrier flight operations.

Flightpath management (FPM) involves the planning, execution, and assurance of the guidance and control of aircraft trajectory and energy, in flight or on the ground (FAA AC 120-123: Flightpath Management, 2022). To accomplish FPM tasks, pilots may form internal representations, known as mental models, of how they expect the external world (e.g., the aircraft, systems, environment) to behave using multiple cognitive skills concurrently with knowledge to process, store, and analyze information (Hardy & Parasuraman, 1997). A cognitive skill is the ability to retain and combine knowledge about a domain and then be able to apply, generalize, combine, and transfer this knowledge to perform complex intellectual tasks (VanLehn, 1996). For example, Air Traffic Control (ATC) may request an aircraft to reduce speed on an arrival. A pilot may use cognitive skills with knowledge to decide what actions need to be made to execute the request and manage the flightpath and aircraft energy accurately and efficiently. Cognitive skills such as information collection, integration, estimation, prediction, and planning would be used to combine, apply, generalize, and transfer knowledge. Knowledge might include information about the aircraft (e.g., its current state, performance, etc.), knowledge of automated systems, knowledge of procedures and policies, and more. Degradation of these cognitive skills and knowledge could affect pilots' abilities to plan, execute, and assure the aircraft's flightpath.

The goal of this research is to provide insight into the potential degradation of cognitive skills for flightpath management in commercial air transport 14 C.F.R. Part 121 flight operations. Three research questions (RQ) are posed towards this objective:

RQ1. Which cognitive skills and knowledge are susceptible to decay and degradation?

RQ2. What are potential reasons cognitive skills and knowledge may be susceptible decay and degradation?

RQ3. What are potential strategies to help mitigate or manage decay and degradation of cognitive skills and knowledge?

To answer these questions, an inventory of cognitive skills for FPM is first provided. The inventory is a list of cognitive skills and knowledge for specific high-level FPM objectives and FPM cognitive tasks. To complete the inventory, data from prior work on the knowledge and cognitive skills for FPM was supplemented with cognitive walkthroughs with pilot subject matter experts (SME) and then aggregated to identify a set of FPM objectives, FPM cognitive tasks, knowledge domains, and cognitive skills.

Secondly, the cognitive skills and knowledge domains most susceptible to degradation are identified. With this inventory as a baseline, a human-in-the-loop (HITL) simulation study evaluated how FPM cognitive skills and knowledge may degrade. The study assessed how B737 and A320 type-rated pilots use their cognitive skills for FPM throughout seven scenarios based on a single flight in either a B737 or A320 simulator. The HITL consisted of two parts: (1) a Cross-Sectional Study using a between-subjects design in which three groups of participants completed seven scenarios designed around a single flight from Phoenix to Los Angeles, and (2) a Longitudinal Study, using a within-subjects design in which participants returned approximately 5 months later to complete the same scenarios. For the Cross-Sectional Study, degradation resulting from time away from flying was assessed by comparing three groups of participants: (1) individuals who meet requirements as defined in 14 CFR 121.439 pilot qualification for recent experience[2], (2) individuals whose last flight was in an A320 or a B737 in the preceding 6-12 months , or (3) individuals whose last flight was in an A320 or a B737 in the preceding 12 – 24 months. Twenty-four participants total completed seven scenarios in their aircraft type. There were eight participants in each of the three groups, with four participants per group for each aircraft type. Cognitive skills were assessed based on exhibited actions and behaviors during the seven scenarios and through a verbal protocol conducted at the end of each scenario. Results suggest potential degradation of declarative and procedural knowledge and cognitive skills such as information collection, integration, and estimation. For the Longitudinal Study, eleven participants from the first study (six from the A320 and five from the B737) returned and completed the seven scenarios again, five months later. Skills were again assessed based on exhibited actions and behaviors during the seven scenarios and through a verbal protocol elicited at the end of each scenario.

The HITL study focused on time away from flying as a potential factor contributing to degradation; however, other potential factors of observed degradation and decay are discussed. Other factors include changes in technology and procedures as well as human factors such as fatigue and skill and knowledge deterioration due to complacency or disuse resulting from overconfidence or trust. Finally, based on the HITL study, strategies to mitigate risk of degradation are proposed. Proposed strategies may help pilots develop, retain, and maintain a degree of proficiency in cognitive skills and knowledge for certain FPM tasks.

This report is organized as follows. The next section, Section 2, describes an inventory of cognitive skills and knowledge for certain flightpath management tasks. Section 3 outlines the objectives of the HITL study based on the inventory of cognitive skills. Section 4 describes the methodology for the HITL study which includes a detailed description of the study design, experimental protocol, participants, data collection, and metrics. Results from the HITL study are detailed in Section 5. Section 6 concludes the report with a summary of results and findings regarding answers to the proposed research questions, and a discussion of the limitations for this work. Please note that throughout this report, attempts were made to be specific when referencing specific flight decks, such as the A320 and B737 flight decks; however, general terminology may also be used to refer to similar systems on both aircraft (e.g., primary flight display or PFD).

2. ESTABLISHING AN INVENTORY OF COGNITIVE SKILLS

In prior work (see Holder, Lubold, & Finseth, 2021), research was conducted to provide a benchmark of the cognitive skills and cognitive processes (see Table 1 for definitions of these key terms) needed for FPM in transport aircraft during 14 CFR Part 121 air carrier flight operations. This prior research involved two SME pilots who participated in a series of cognitive walkthroughs to establish the benchmark. The tasks involved seven different phases of flight and two medium size aircraft (A320 and B737NG); cognitive

[2] 14 CFR § 121.439 Pilot qualification: Recent experience - https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-121

processes were identified for three of the phases—Preflight Briefing, Initial Climb, and Descent. The initial results from this evaluation identified nineteen cognitive skills that are used by pilots for FPM. In addition, the cognitive process models needed for FPM were all very similar, regardless of the two aircraft types, task, phase of flight, or increased operational complexity.

Table 1. Definitions of key terms.

Term	Definition
Cognitive Skills	The ability or proficiency to retain and combine knowledge about a domain and then be able to apply, generalize, combine, and transfer this knowledge to perform complex intellectual tasks (VanLehn, 1996).
Cognitive Process	A series of operations (e.g., perception, memory) that occur in the mind involving the creation and manipulation of representations of information (Krch et al., 2011).
Mental Model	A representation of information in the mind where representations are of the world and can include oneself, objects, data, and situations (Norman, 1983; Gentner & Stevens, 2014).
Cognitive Task	A task in which correct and appropriate processing of information in the mind (e.g., through a cognitive process) contributes to successful performance of the task (Carroll, 1993).
Metacognitive Skills	Beyond execution of a cognitive process, a metacognitive skill is the ability to understand, control, and manipulate one's own cognitive process.
Schemas	A framework or scaffold for specific types of objects, concepts, or activities; facilitates processing of experiences (Brewer, 1987; Westbrook, 2006).
Heuristics	Mental shortcuts that allow individuals to solve problems quickly.

Note: Defining cognitive process, cognitive skill, and cognitive task is challenging given the definitional variation in the literature. Standardized definitions and variations should be addressed in future work.

The data from this prior research was comprehensive but unaggregated. Furthermore, it was based on perspectives from two SMEs. In this report, previously collected data was supplemented with additional SME reviews to capture information that may have been missed, to identify any differences in skills relevant to the pilot monitoring (PM) and pilot flying (PF), and to refine the identified objectives, tasks, knowledge, and skills. The demographics for the additional SMEs who were consulted in this report are provided in Table 2.

Table 2. Demographics for pilot subject matter experts for finalizing inventory.

	Type Rating	**Qualification**	**Total Flight Hours Experience**
P1	Airbus A320	Captain	7,500
P2	Airbus A320	Captain, Check Pilot	10,500
P3	Boeing 737	First Officer	7,000
P4	Boeing 737	Captain	15,000

P5	Airbus A320 and Boeing 737	Captain, Check Pilot	9,000

With the additional insights, the findings were then aggregated and summarized into a single reference material. This single reference material, called here the **Cognitive Skills Inventory**, provides a documented set of FPM objectives, FPM cognitive tasks, knowledge, and cognitive skills. The inventory is a hierarchical list. For each FPM objective, a set of FPM cognitive tasks to accomplish the objective are documented. For each FPM cognitive task, the knowledge and cognitive skills needed to perform that task are then documented. Figure 1 illustrates this hierarchal organization. In the rest of this section, a summary of all the identified objectives, tasks, knowledge and skills. The complete inventory can be found in Appendix A – Cognitive Skills Inventory.

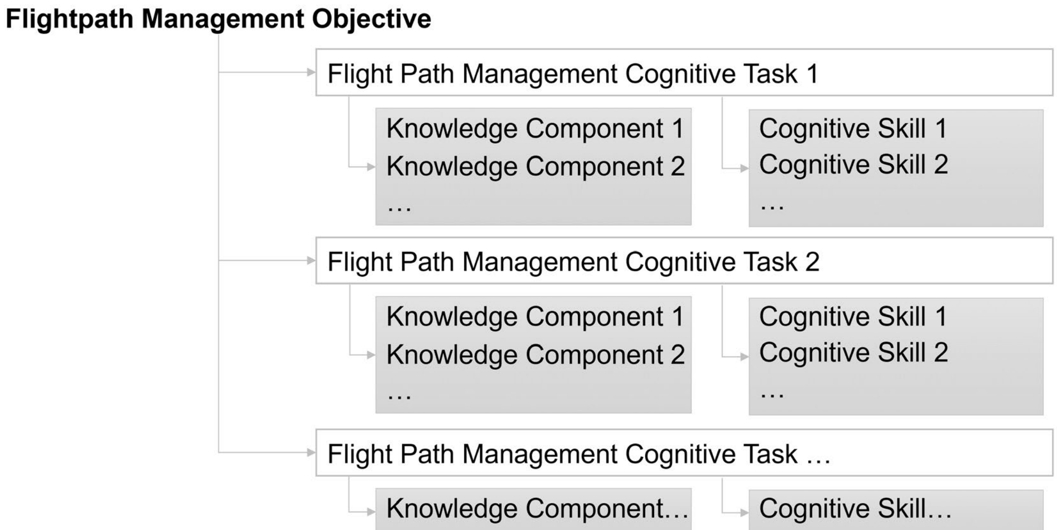

Figure 1. The cognitive skills inventory is organized by flightpath management objective, with each FPM objective associated with a set of FPM cognitive tasks, and each FPM cognitive task associated with a set of knowledge components and cognitive skills.

It is important to note the inventory was developed based on SME experience of the Airbus A320 and Boeing 737 aircraft. It is known Airbus and Boeing have different design philosophies. Airbus employs the philosophy that automation should allow the operator to use the safe flight envelope to its full extent (Spitzer et al., 2015; Airbus, 2017). This philosophy is incorporated into automation design, through Airbus's flight control laws. In Normal and Alternate Law, the flight crew are able to manipulate the flight controls but are unable to make any input which would result in the aircraft operating outside a pre-defined set of parameters (Ibsen, 2009). Boeing's philosophy emphasizes the pilot's manual control of the aircraft (Spitzer et al., 2015; Ibsen, 2009), and the flight crew are able to make inputs with a wider set of parameters.

The differences in these philosophies are reflected in how the A320 and B737 systems gather data, compile it, and present it to the pilot. The design philosophies also affect the physical layout of the flight decks, and the implementation of automation with respect to flight controls. While the set of FPM objectives, FPM cognitive tasks, knowledge, and cognitive skills are applicable to both aircraft types, the design philosophy impacts *how* pilots execute cognitive tasks. Pilots will need to use systems that operate differently between the A320 and B737; consequently, the specific knowledge that pilots need can differ. The categories or types of knowledge and sources of knowledge are the same. For example, both A320 and B737 pilots need knowledge of airplane performance as can be obtained from the performance or operational information section of the Aircraft Flight Manual / Pilot's Operating Handbook (AFM/ POH). The specific knowledge of the airplane's performance is what then differs, depending on the aircraft type.

FPM Objectives

The Cognitive Skills Inventory documents four FPM objectives, as shown in Table 3. There is not a rank or priority for these objectives. The relevancy of an objective may vary depending on the phase of flight. For example, Objective A, forming an understanding of the plan for the flight and ensuring the airplane is prepared appropriately, is particularly relevant during the preflight briefing and approach preparation phases of flight while Objective C, assuring the current position (lateral and vertical) of the aircraft is correct per plan is more relevant during other phases of flight, such as initial climb and departure.

Table 3. FPM objectives and applicable phases of flight where these objectives are applied. There is not an ordered priority or rank to the objectives.

FPM Objective ID (used for reference)	**Description**	**Relevant Phases of Flight**
A	Form an understanding (mental model) of the plan for the flight and make sure the airplane is prepared appropriately	Preflight Briefing Approach Prep
B	Ensure joint of the plan for the flight (flight crew) understanding	Preflight Briefing Approach Prep
C	Assure current position (lateral & vertical) and energy state is correct per plan, including proximate constraints.	Initial Climb/Departure Cruise Climb / En-route Cruise Later Cruise Descent / Arrival Approach, Taxi
D	Assure trajectory (lateral & vertical) and energy trend is correct per plan, including upcoming/future constraints.	Initial Climb/Departure Cruise Climb / En-route Cruise Later Cruise Descent / Arrival Approach, Taxi

FPM Cognitive Tasks for FPM Objectives

For each of the objectives there is a set of cognitive tasks that is associated with that objective as shown in Table 4. These tasks enable the completion of the objectives. For Objectives 3 and 4, the tasks are cyclical and repetitive. Pilots typically perform the tasks for FPM Objective 3 and FPM Objective 4 very quickly, again and again throughout the flight, though frequency can depend on the context and scenario.

Table 4. FPM cognitive tasks as associated with the documented set of FPM objectives.

FPM Obj A Cognitive Tasks	FPM Obj B Cognitive Tasks	FPM Obj C Cognitive Tasks	FPM Obj D Cognitive Tasks
• Check local knowledge of the route, area, airplane, airport, and destination. • Check winds and weather. • Check expected altitudes and wind variation. • Check weight. • Check fuel plan and reserves. • Check block times and fuel burn. • Check maintenance status of the airplane. • Check flight plan against route using all information sources and systems, including notice to air missions (NOTAM)s	• Brief the flight crew and confirm that they have the same big picture mental model.	• Identify the airplane's actual lateral position, actual vertical position, and actual energy state. • Identify the airplane's intended current lateral position, vertical position, and energy state including proximate constraints. • Compare the airplane's actual lateral position, actual vertical position, and actual energy state to intended current lateral position, vertical position, and energy state.	• Identify the airplane's lateral trajectory, vertical trajectory, and energy trend. • Identify the airplane's intended lateral trajectory, vertical trajectory, and energy trend including upcoming/future constraints. • Compare the airplane's actual lateral and actual vertical trajectory, and actual energy trend to intended current lateral trajectory, vertical trajectory, and energy trend. • Decide on correct course of action to adjust (if needed) flightpath and energy controls.

Examples of FPM Knowledge for FPM Cognitive Tasks

To complete the cognitive tasks associated with each objective, pilots need extensive knowledge. Much of this knowledge is declarative, which means that it consists of facts that can be stated (Anderson, 1982). Some of this knowledge is procedural. Procedural knowledge refers to the knowledge of "how" to perform a task. In addition to the declarative and procedural knowledge, there is also generic and abstract knowledge that is learned from training and from experience. Mental schemas are an example of this kind of knowledge. Mental schemas are mental representations that are used to process experiences, organize information, and retrieve information by providing a framework or scaffold for specific types of objects, concepts, or activities (Seel, 2012). For example, pilots can have a schema representing how an airplane behaves in a steady-state, constant speed climb, and how changes to the environment might affect this behavior. This schema might include expectations for the relationships between temperature, weight, and an airplane's climb behavior. When a pilot is physically present in an airplane performing a climb maneuver, they will populate or "fill in" the schema with information from their current experience.

Examples of the types of declarative, procedural, general and abstract knowledge that pilots need for FPM are listed in Table 5, Table 6, and Table 7. The intention behind the provided list is not for the list to be completely exhaustive, but for it to provide a sense of the breadth of knowledge pilots need with specific examples of the materials, systems, and sources where this knowledge can be obtained. The sources for most types of declarative knowledge and procedural knowledge for completing FPM cognitive tasks are available to pilots (e.g., pilots have access to these sources of knowledge as and when they need them), frequently trained, and/or evaluated. For example, declarative knowledge regarding the performance of the airplane can be obtained from the AFM; declarative knowledge of the functions of the FMS and interactions with autoflight modes can be learned from the FMS Pilot User's Guide and Flight Crew Operating Manual.

Table 5. Examples and sources of declarative knowledge to complete FPM cognitive tasks.

Examples of Declarative Knowledge	Sources of Declarative Knowledge
Airplane performance	Performance or operational information section of the Aircraft Flight Manual / Pilot's Operating Handbook (AFM/ POH)
Company-specific procedures	Company manuals and training documentation
Aeronautical, operational, regulatory, systems, safety, emergency, and human factors knowledge	Airline Transport Pilot and Type Rating for Airman Certification Standards (ACS); aeronautical publications
Functions of the FMS, FMS interactions with autoflight modes, and other functionality	FMS Pilot's Users Guide and Flight Crew Operating Manual
Functions and operations of the weather radar, Traffic Alert Avoidance System (TCAS)/ Automatic Dependent Surveillance-Broadcast (ADS-B), and Enhanced Ground Proximity Warning System (EGPWS) equipment	Company manuals, aircraft manuals, and training documentation
Autoflight system, including FD, AP, A/T, FMAs	Company manuals and training documentation
Flight control and engine control systems, including normal usage and limitations	Company manuals, aircraft manuals, and training documentation
Standard flight profiles for all phases of flight	Company manuals, aircraft manuals, and training documentation
Standard, company-specific actions and callouts for each "maneuver" component of a flight. For example, takeoff, climb, cruise, descent, approach, landing, and all the sub-variants such as the profile for an instrument landing system (ILS) approach versus the profile for a GPS approach versus the profile for visual approach.	Company manuals, aircraft manuals, and training documentation
Local knowledge about the route, area, airplane, airport, and destination	Each pilot will have their own set of local knowledge that is compiled from experience and from external references and is incorporated into their mental model.

Table 6. Examples and sources of procedural knowledge to complete FPM cognitive tasks.

Examples of Procedural Knowledge	Sources of Procedural Knowledge
How to use systems to explore implications of changes to the flightpath and effects on the flightpath	FMS Pilot's Users Guide, training, experience
How to execute company-specific procedures	Company manuals, aircraft manuals, training documentation, training, and experience
Heuristics that are applicable to the task and phase of flight, and how and when to apply them	Company manuals, aircraft manuals, training documentation, training, and experience
When (and declarative knowledge of where) to find information on: • ND (e.g., heading, waypoints, predictions, restrictions, winds, weather, terrain, traffic) • FMS (e.g., flight plan routing, vertical plan and predictions, fuel predictions, etc.) • PFD (e.g., attitude, altitude, vertical speed, airspeed, heading, FMA) • ECAM/EICAS (e.g., thrust, engine parameters, system status) • Charts (e.g., standard instrument departure (SID)/ Standard Arrival Route (STAR)/Enroute waypoints, restrictions)	Company manuals, aircraft manuals, training documentation, training, and experience

Table 7. Examples and sources of general and abstract knowledge to complete FPM cognitive tasks.

Examples of General and Abstract Knowledge	Source of General and Abstract Knowledge
Mental schema for the effects of factors like aircraft weight and atmospheric conditions on the performance of the specific airplane type	Training and experience combined with company manuals, aircraft manuals, and training documentation
Mental schema for how different factors (e.g., environmental factors like icing) may influence how an aircraft handles and characteristics associated with how the aircraft handles	Training and experience combined with company manuals, aircraft manuals, and training documentation
Mental schemas for different weather patterns that model the effects of those patterns on the flightpath. Strategies for dealing with those weather patterns	Training and experience combined with company manuals, aircraft manuals, and training documentation
Mental schema for how airplanes fly and specific aircraft aerodynamic tendencies – i.e., the interconnected relationships between attitude, thrust, aircraft configuration, and performance, along with the effects and uses of all associated controls.	Training and experience combined with company manuals, aircraft manuals, and training documentation

Examples of FPM Cognitive Skills for FPM Cognitive Tasks

Pilots use cognitive skills with knowledge to accomplish FPM cognitive tasks. Nineteen cognitive skills were identified in prior work; based on additional SME feedback, these nineteen skills were refined to ten skills. General definitions of cognitive skills are provided in Table 8. Depending on the phase of flight, FPM objective, and FPM cognitive task, these skills may be applied differently. For example, during pre-flight, pilots may exercise the cognitive skill of planning to formulate a plan for the flight based on the flight release, weather, fuel, weight, and more. During the arrival, pilots may be exercising planning more tactically, formulating a plan for how to adjust (if needed) flightpath and energy controls to meet upcoming and future constraints.

Table 8. Cognitive skills needed for FPM.

Skill	**Example of Description** (Description can change slightly depending on the phase of flight and task)
Collection	Ability to seek out information from numerous systems and sources, from knowledge, etc.
Assessment	Calculate or determine the value or importance of a piece of information as it is relevant to an FPM task
Integration	Put multiple pieces of information together towards an idea, concept, solution
Interpretation	Analyze and draw conclusions from current visual and audible data by utilizing and drawing on knowledge and schemas
Estimation	Calculate a value, size, amount, or distance without actual measurement
Prediction	Project occurrence of future events based on estimation of incomplete information in the present
Comparison	Assess multiple pieces of information and how they complement, explain, or refute one another; change detection
Planning	Formulate and identify a strategy and set of tasks or actions
Communication	Identify when and how to explain or discuss information with others
Mental Construction	Utilize collected interpreted and estimated data to build a mental model (i.e., a mental image or visualization) of a situation, problem, or concept

3. HITL STUDY OBJECTIVE

The objective of the HITL is to provide insight into which FPM cognitive skills and knowledge are susceptible to degradation, identify potential reasons why skills and knowledge for FPM may degrade, and provide insight into potential mitigations. The Cognitive Skills Inventory documents four FPM objectives, sixteen high-level FPM cognitive tasks, and ten cognitive skills along with examples of declarative, procedural, and general or abstract knowledge needed to execute the cognitive skills, cognitive tasks, and FPM objectives. To focus the design of the HITL, literature reviews from prior work were consulted, and additional supplementary literature was reviewed. Prior literature reviews included work by Barrett and Schroeder (2018) who conducted an extensive literature review of existing publications and a review of incidents and accidents from the perspective of cognitive skills gaps that may have contributed to events (Holder, Lubold, & Finseth, 2021).

Based on these reviews, six of the FPM cognitive skills were chosen as the focus of the study: collection, integration, estimation, prediction, planning, and communication. These skills were chosen for two reasons. First, based on the inventory, pilots use all six of these skills to execute FPM cognitive tasks in preflight, takeoff, climb, cruise, arrival, and approach. Being able to compare application of these same skills across different phases of flight can provide insight into how skills might degrade in different contexts. Secondly, these six cognitive skills represent a broad spectrum, where degradation may occur at varying levels. Cognitive skills such as estimation, prediction, and planning support moderate to high cognitive tasks and therefore may be more susceptible to decay, because they require conscious control and more mental resources (Wang et al., 2013; Mumaw et al., 1994; Carlson et al., 1990). In comparison, cognitive skills such as information collection and integration may be less susceptible to decay because, in some contexts, they are more likely to be automatized. Automatized means the skills have become automatic or unconscious through repeated and consistent use over time (Sun & Zhang, 2004). Automatized skills are thought to be deeply ingrained, making them more resistant to degradation over time. For example, collection and integration of airspeed, altitude, pitch, and heading from the PFD to identify and verify the aircraft's current lateral and vertical position may be automatized skills and therefore less susceptible to degradation. When automatized skills do degrade, it can be subtle, such as in terms of speed or precision. There is also the possibility for contexts in which skills like information collection and integration appear to be automatized, but there is still some conscious control and mental resources that make the skills more susceptible to degradation.

For knowledge, prior work indicates that declarative knowledge may degrade more quickly, while procedural knowledge degrades more slowly, and abstract knowledge degradation can vary based on complexity. The study focus therefore included examples of all three kinds of knowledge to assess potential degradation of each. FPM declarative, procedural, and abstract knowledge are related to several factors, including the aircraft type and the operational context, such as phase of flight, environment, flight route, systems available, and the state of the aircraft. Therefore, to analyze degradation, aircraft types and contexts were defined. First, the Airbus A320 and Boeing 737 were selected for analysis of potential degradation since these two aircraft were previously used to help form the inventory and are common in the airline industry. Secondly the inventory was drafted based on normal operations with no emergencies. Therefore, knowledge for normal operations based on a single flight in an A320 or B737 was the initial high-level context. Scenarios were then designed around cognitive tasks in each phase of flight. The focus of the scenarios was on eliciting pilot actions, behaviors, and perspectives related to the six cognitive skills and the three different types of knowledge needed to support application of those skills within specifically defined contexts (see Section Scenario Design).

Finally, the reviews highlight that in other domains, cognitive skills and knowledge have been found to deteriorate for a variety of reasons that include changes in routine, lack of continual training, aging, and time away from the task environment (Arthur et al., 1998; Cant et al., 2021; Park et al., 2022; Woodman et al., 2021). In this work, time away from the task environment was selected as the main factor to evaluate for its potential to contribute to cognitive skill and knowledge degradation. Other factors are considered where the results may support them.

4. HITL STUDY METHODOLOGY

A HITL study was used in this work to investigate the three research questions posed regarding degradation due to time away from flying. The HITL consisted of two parts: (1) a between-subjects evaluation in which three groups of participants completed seven scenarios designed around a single flight from Phoenix to Los Angeles, and (2) a within-subjects evaluation in which participants returned approximately 5 months later to complete the same scenarios. The within-subjects evaluation supports findings from the between-subjects study. Data collection tools and techniques included use of one flight training device simulator, one research-based simulator, video and audio recordings, experimenter observations while sitting in the jump seat of the simulators, verbal feedback from the participants, and self-reported answers to questionnaires. The study was reviewed and approved by the independent Institutional Review Board Arclight, Inc. and by the FAA Institutional Review Board as an expedited approval.

Scenario Design for Cross-Functional Study

The research team created seven normal operational scenarios around a single flight from Phoenix to Los Angeles (see Figure 2) to elicit observable pilot actions, behaviors, and perspective. The seven scenarios were based on prior work by the team that found that the skills of information collection, integration, estimation, prediction, planning and communication are required throughout various phases of flight to manage the flightpath of an aircraft. The scenarios were designed around a single flight to understand the creation and maintenance of a pilot's mental model for a flight, from when they receive the flight release prior to the pre-briefing through the briefing, takeoff, climb, cruise, arrival, approach, and landing. Scenarios based on a single flight also more closely mirrors real-world operations, where pilots will prepare and conduct a flight in its entirety from receiving the release to landing the aircraft and taxing to the gate. A single flight avoids potential disruption of the pilot's cognitive processes which could occur if the scenarios took place across different routes and the phases of flight did not follow operational expectations.

Route Details

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KPHX Rwy 7L MESSI ESTWD BRUEN2 ILS 7R KLAX
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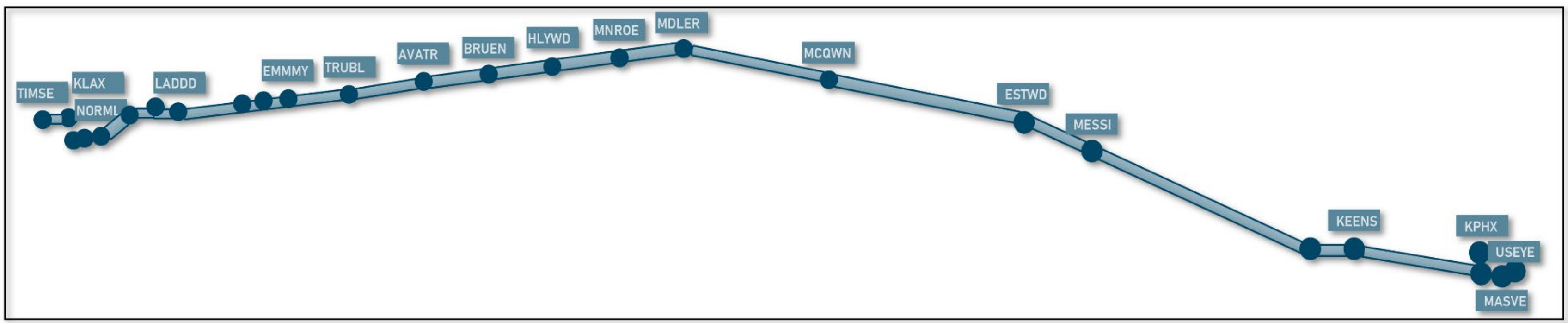


Figure 2. A top-down view of the flight plan, with the routing details, and flightpath. The flight plan shows origination of a flight at Phoenix Sky Harbor International Airport (KPHX), the departure airport, and termination at Los Angeles (KLAX), the destination airport. Also depicted is the direction of flight over a geographical area with waypoints along the route of flight.

Table 9 below provides the scenario titles, the high-level objective of each scenario, and a short description that provides when the scenario started and ended. Each scenario is described in more detail below the table. The flight release, aeronautical publications, and checklists provided to the pilots can be found in Appendix C – Flight Release, Appendix D – Aeronautical Publications, and Appendix F – Checklists.

Table 9. Scenario ID, scenario title, scenario objective, and brief description of each scenario.

Scenario ID	Scenario Title	Scenario Objective	Short Description of Scenario
Scenario 1	Flight Plan Review and Assessment	Assess cognitive skills and knowledge for evaluating a flight plan and constructing a mental model of the flight and the flightpath.	The scenario started in the briefing room when participants received the flight release and aeronautical publications. Participants were instructed to review the release and state when they were done. The scenario ended when the participant indicated they had completed their review of the documents and were ready to proceed to the simulator.
Scenario 2	Pre-flight Preparations and Flight Deck Setup	Assess cognitive skills and knowledge for preparing the aircraft, constructing a mental model of the flight and the flightpath preflight, and briefing the crew.	The scenario started in the simulator with the aircraft parked at the gate in Phoenix. Participants were instructed to accomplish and verify all tasks they would normally do at the gate. The scenario ended when the participant indicated they were ready to taxi but had not completed the taxi checklist.
Scenario 3	Area Navigation (RNAV) Departure from Phoenix (KPHX)	Assess cognitive skills and knowledge for planning and controlling airspeed, altitude, thrust, and trajectory during takeoff.	The scenario started with the aircraft holding short of runway 7L. Participants were instructed to proceed with the flight as per normal operations starting with the taxi checklist. The scenario ended one minute after the aircraft crossed 8000 feet (ft).
Scenario 4	Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude	Assess cognitive skills and knowledge for responding to an air traffic control intervention that affects flightpath management (FPM), including planning and controlling airspeed, altitude, thrust, and trajectory during later climb.	The scenario started with the aircraft climbing out on the departure at 16,600 ft. Participants were instructed to resume the flight, starting with any activities they would have accomplished between 8000 and 16,600 ft (e.g., when crossing 10,000 ft). At one minute past FL280 participants received a request from ATC to cross FL320 in two minutes or less. The scenario ended 1 minute after the aircraft crossed FL320[3].

[3] If participant told ATC they could not make it to FL320 in two minutes or less, ATC leveled aircraft at FL300. ATC then cleared aircraft to FL320 after 1 minute and scenario ended when aircraft reached FL320.

Scenario 5	Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise	Assess cognitive skills and knowledge for managing fuel and effects of fuel burn on flightpath.	The scenario started with the aircraft in cruise at FL340. Participants were instructed to resume the flight. Participants received an Aircraft Communications Addressing and Reporting System (ACARS) request shortly after resuming the flight notifying them of a potential hold. ATC then issued a hold to participants. The scenario ended five minutes into the holding pattern.
Scenario 6	Energy Management during RNAV Arrival Descent to Los Angeles (KLAX)	Assess cognitive skills and knowledge for responding to air traffic control interventions that affect flightpath management (FPM), including planning and controlling airspeed, altitude, thrust, and trajectory during later climb.	The scenario started with the aircraft having exited the hold but still in cruise, 30 miles from top of descent. Participants were instructed to resume the flight. At the top of descent, participants received a clearance to descend. ATC requested them to slow to 250 knots with permission to resume normal speeds later on the published profile. Scenario did not end; participants transitioned into the next scenario with no interruption.
Scenario 7	Navigation Source Transition during Arrival-to-Approach Operations	Assess cognitive skills and knowledge for planning and controlling airspeed, altitude, thrust, and trajectory during a normal ILS approach.	The scenario started with the aircraft in the approach. Scenario ended when the aircraft had landed and come to a complete stop on the runway (participants were instructed to bring the aircraft to a stop).

Scenario 1: Flight Plan Review and Assessment
This scenario took place in the briefing room, after the participant signed a consent form and received an overview of the study and a safety briefing. This scenario began with the study participant receiving a paper version of the flight release, including minimum equipment list (MEL) items, performance data, and an electronic flight bag (EFB) pre-loaded with the necessary aeronautical publications. Participants were instructed to review the release and state when they were done. The scenario ended when the participant indicated they had reviewed all documents were ready to proceed to the simulator.

The goal of this scenario was to assess the cognitive skills and knowledge for reviewing a flight release and constructing a mental model of the flight and the flightpath. To do this, flight planning software generated a release for a flight between Phoenix and Los Angeles. The route, alternate, Phoenix Automatic Terminal Information Service (ATIS), Meteorological Terminal Aviation Routine Weather Report (METAR)s, fuel loading, weight, passenger loading, notice to air missions (NOTAMs), and MEL items were included in the release, and aeronautical charts were provided to the participants. The study participant was expected to utilize knowledge (see examples in Table 5) and the cognitive skills of information collection, integration, estimation, prediction, and planning with the provided information to develop a mental model of the flight and flightpath.

The weather in Phoenix could be considered warm or hot, at 35°C, with clear skies (WX 030/10 FEW120 35°C 29.88). However, the METAR for the weather in Los Angeles indicated that weather for KLAX was overcast with two and a quarter mile visibility (WX 360/15 OVC10 TOP60 2 1/4SM 15°C 29.99), and an alternate was provided (San Francisco International Airport (KSFO)). The release indicated the aircraft would have 45 minutes of reserve fuel and one hour of extra fuel. The participants should use the information regarding the alternate and the weather at KLAX to develop a mental model of the flight operation before it occurs and during the flight operation, where they may need to re-route to their alternate. This model should impact how they assess fuel and their expectations regarding the route. In another example, the participants were provided with a long list of NOTAMs. Some NOTAMs were applicable Phoenix (KPHX), the route of flight, and arrival airport. Specific to the LA area, there were several NOTAMs that mention construction (e.g., flagged cranes around 200 – 250' tall). The extent to which they collect, integrate, and apply this information to develop some level of awareness of the surrounding LA area indicates how they use this information to help build a mental model of the flight operations.

Scenario 2: Pre-flight Preparations and Flight Deck Setup

Scenario 2 was the first scenario in the simulator. This scenario started with the aircraft parked at the gate A5 in Phoenix (KPHX). Upon entering the simulator, participants were given time to get comfortable and familiarize themselves with the flight deck. The flight plan was pre-loaded for simplicity, as different pilots from different operators may have different operational procedures and expectations for obtaining and loading the flight plan that could be challenging to simulate accurately. For similar reasons, the engines were already started, and study participants were informed the pre-departure clearance had already been provided. The departure clearance was provided verbally. The study participant was instructed to review the loaded profile, confirm their mental model of the flight and flightpath, prepare the flight deck by completing necessary checklists, and ensuring that they have the same plan for the flight, potential threats, and deviations as their PM. This includes accomplishing and verifying all tasks they would normally do at the gate. The scenario ended when the participant indicated they were ready to taxi but had not completed the taxi checklist.

The goal of this scenario was to assess participant knowledge and cognitive skills of information collection, integration, estimation, prediction, planning, and communication for verifying the loaded flight plan, preparing the flight deck, and briefing the crew. With the loaded flight plan, the flight management system (FMS) generated a pre-built flight profile based on a predicted flightpath and performance data from the release. The participant should collect information from the KEENS2 DEPARTURE (see Appendix D RNAV Departure – KEENS2), BRUEN2 ARRIVAL (see Appendix D RNAV Arrival – BRUEN2), and the loaded flight plan in the FMS, and integrate this information to verify the loaded flight plan against the release and charts in EFB. For example, participants should collect the top altitude they are cleared to (8000 ft) and check that this altitude is entered in the mode control panel correctly. Participants should note and be prepared for constraints along the departure; they should collect and verify the box reflects the altitude constraint (above 7000) and speed constraint (220 knots) at MASVE on the KEENS2 departure and that the aircraft will be able to make these constraints.

The participant should also use knowledge, the skills of collection and integration, and provided checklists to prepare the flight deck and complete preflight and pushback checks. Participants should collect the altimeter setting of 29.88 (in. Hg) at Phoenix, weight, and fuel information, and check these numbers are entered correctly. Estimation, prediction, planning, and communication should be applied with the generic briefing guide to conduct the departure briefing. This includes talking about threats, performance considerations, rejected takeoff considerations, and the planned departure. Terrain and weather may be topics touched on during the briefing, depending on the participant's mental model of the flight, knowledge, and skills.

Scenario 3: Area Navigation (RNAV) Departure from Phoenix (KPHX)

Scenario 3 started with the aircraft holding short of runway 7L at KPHX; the taxi component of the flight was excluded to allow time to focus on in flight scenarios and because realistic replication of taxi operations relevant to this study in an aircraft simulator can present difficulties. Participants were instructed to proceed with the flight starting with checklists related to taxi and proceeding with the rest of the flight as per normal operations. Participants were encouraged to mentally simulate the taxi component of the flight, to ensure that any tasks they would normally do during that part of the flight would not be missed as a result of omitting taxi and to facilitate the participant's mental model of the flight. The scenario ended after the takeoff and initial climb, when the aircraft was in the climb, one minute after the aircraft crossed 8000 ft.

Scenario 3 focused on the cognitive skills and knowledge needed for planning and controlling airspeed, altitude, thrust, and trajectory during takeoff and initial climb. The participant should complete checklists and then contact Phoenix Tower. Phoenix Tower cleared participants for takeoff via runway 7L, RNAV to FUTEP (see Appendix E for the specific ATC verbiage). Participants should then execute the takeoff and initial climb leveraging the FMS computed profile and aeronautical publications, particularly the departure procedure. Figure 3 shows an excerpt from the departure procedure found in Appendix D RNAV Departure – KEENS2. The figure depicts the takeoff and initial climb of the departure procedure, including climbing at heading 078° to an altitude of 1635 feet, then direct to the waypoint FUTEP, 132° to waypoint AZCRD, then on track 199° to waypoint USEYE, and then 264° to cross waypoint MASVE at or above 7000 feet and at or below 220 knots. After takeoff at 2500ft mean sea level (MSL), participants were handed off to Phoenix Terminal Radar Approach Control (TRACON).

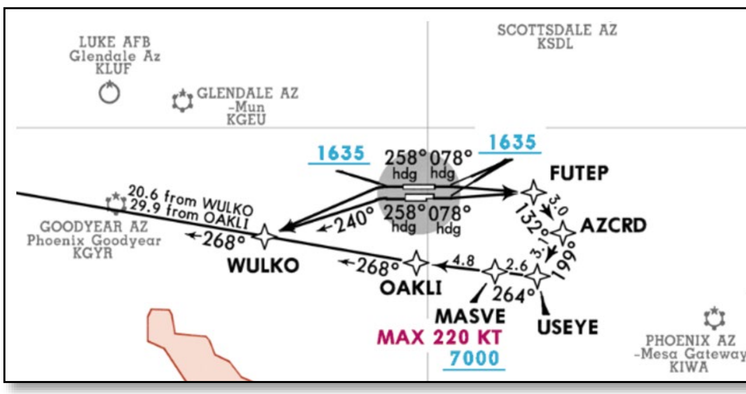


Figure 3. Excerpt from departure procedure (Appendix D RNAV Departure – KEENS2).

Used in Scenario 3 to execute takeoff and initial climb according to procedure: heading 078° to 1635 feet, direct to FUTEP, 132° to AZCRD, then on track 199° to USEYE, and then 264° to cross waypoint MASVE at/above 7000 feet and at/below 220 knots.

The participant should use the cognitive skills of information collection, integration, estimation, prediction, planning, and communication with knowledge to execute a normal takeoff and initial climb. This includes collecting information such as airspeed, altitude, climb rate, flight modes, and constraints from the PFD, ND, and FMS. Collected information is integrated to manage the flightpath. Skills such as estimation, prediction, and planning may be used with knowledge of factors such as temperature, aircraft weight, and terrain to consider any potential impact to aircraft performance. Knowledge with collection, integration, estimation, and planning may be used to maintain awareness of automated systems including autopilot (AP), autothrottle/autothrust (A/T), flight director (FD), lateral navigation (LNAV), and vertical navigation (VNAV), effects of these automated systems on the flightpath, and knowledge of how to enable, interact, and use these automated systems to manage the flightpath. Local knowledge, planning, and prediction may be used to consider whether to ask ATC for higher after reaching the cleared to altitude of 8000ft.

Scenario 4: Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude

Scenario 4 started with the aircraft continuing the climb on the RNAV KEENS2 departure at an altitude of 16,600 ft after the WULKO waypoint. Participants were instructed to resume the flight, starting with any activities they would have accomplished between 8000 and 16,600 ft, such as a climb checklist. Participants were communicating with Phoenix TRACON at the start of the scenario and were handed off to Albuquerque Air Route Traffic Control Center [ARTCC](ZAB) shortly after the scenario started. ZAB initially cleared participants to FL320, and then at FL280, participants were cleared to their final cruise altitude of 340 and received a request from ATC to cross FL320 in two minutes or less. The scenario ended one minute after the aircraft crossed FL320.

The goal of this scenario was to assess the cognitive skills and knowledge needed to effectively manage the flightpath while responding to the ATC intervention. To decide how they respond to the ATC request and to control airspeed, altitude, thrust, and trajectory during latter climb, participants should use knowledge of aircraft performance at high altitude, knowledge of tradeoffs between airspeed and climb rate, and skills of collection, integration, estimation, prediction, planning, and communication. Participants should collect time information such as target time to reach the constraint and the current time, aircraft current altitude, target altitude, aircraft current airspeed, target airspeed, and aircraft's current rate of climb. Integrating this information, participants should estimate the time they have left to make the constraint, the altitude they have left to climb, the target rate of climb they need, and potentially the effect on airspeed of attempting to meet ATC's request.

Scenario 5: Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise

Scenario 5 started with the aircraft in cruise at FL340 near the ESTWD waypoint. Participants were instructed to resume the flight and were informed they were still communicating with Albuquerque ARTCC (ZAB). Upon resuming the flight, ZAB handed the participants off to Los Angeles ARTCC (ZLA). Thirty miles from the MCQWN waypoint, participants received an ACARS message from dispatch notifying them to expect a hold at MDLER. Content of ACARS message was "WX below CAT 1 mins. Expect HOLD at MDLER due to traffic." When the aircraft was 25 miles from MDLER, ZLA issued the hold at MDLER and informed participants to expect further clearance in 55 minutes. The scenario ended five minutes into the holding pattern.

This scenario focused on assessing cognitive skills and knowledge for navigating a hold, managing fuel, and estimating the effects of fuel burn on the flightpath to make decisions about the flight. Participants should collect and integrate information from the RNAV Arrival BRUEN2 aeronautical publication to enter the hold in the FMS. An excerpt from this chart is shown in Figure 4; this figure shows the published hold at MDLER and information such as the inbound course and the leg distance for the hold that participants would need to collect to enter the hold correctly in the FMS. After entering the hold in the FMS, participants should use information collection and integration to verify that the programmed hold matches the published hold. They may use the ND to visually compare the shape and location of the programmed hold to the aeronautical publication.

Participants should then use the cognitive skills of information collection, integration, estimation, prediction, and planning with knowledge to decide if they can hold for as long as they may need to or if they should go to their alternate of San Francisco (KSFO). Information collection may include collecting information from aircraft systems on current fuel and fuel burn, from the release, and talking to dispatch to collect information about other potential alternates and additional insight into the weather and situation at KLAX. Participants should make a plan for the hold scenario that includes both tactical and strategic components; for example, how long they are going to hold for, what kind of information or status updates are they monitoring, and other factors that are relevant to their plan.

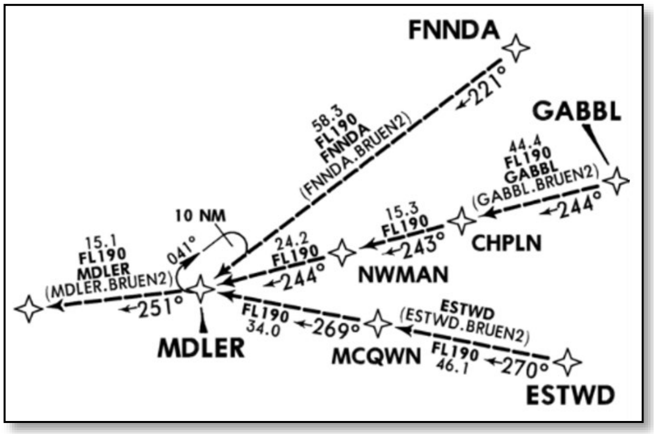


Figure 4. Excerpt from arrival procedure (Appendix D RNAV Arrival – BRUEN2) showing published hold at MDLER.

Used in Scenario 5 to collect information about the published hold at MDLER, including the inbound course of 221° and 10NM legs for the hold.

Scenario 6: Energy Management during RNAV Arrival Descent to Los Angeles (KLAX)

Scenario 6 started with the aircraft in cruise at FL340 30 miles from top of descent near the MNROE waypoint. For reference to the waypoints described in this scenario, Figure 5 shows an excerpt from the arrival procedure which can be found in Appendix D RNAV Arrival – BRUEN2. At the beginning of this scenario, participants were informed that the weather had lifted, thus they had exited the hold, and they were provided with an updated ATIS for KLAX consistent with the original release (WX 360/15 OVC10 TOP60 2 1/4SM 15°C 29.99). Participants were communicating with Los Angeles ARTCC (ZLA) upon resuming the flight, and ZLA cleared participants for the BRUEN2 arrival (RNAV) when the aircraft reached the top of descent near the HYLWD waypoint. ZLA provided a handoff to Southern California Terminal Radar Approach Control Facility (SOCAL) as the aircraft crossed the BRUEN waypoint. Upon contacting SOCAL, SOCAL advised participants to expect vectors to the instrument landing system (ILS) approach to runway 7R at KLAX and issued a speed constraint. The speed constraint reduced aircraft speed from 280 knots to 250 knots until crossing over JOELZ; after crossing JOELZ, aircraft should resume published speeds. The participants should cross NORML at or above 6000 ft at 220 knots. For data analysis, the scenario ended when participants crossed the NIKEY waypoint; however, the scenario was not physically stopped at this point. Participants continued to fly the aircraft and transitioned into the next scenario with no interruption.

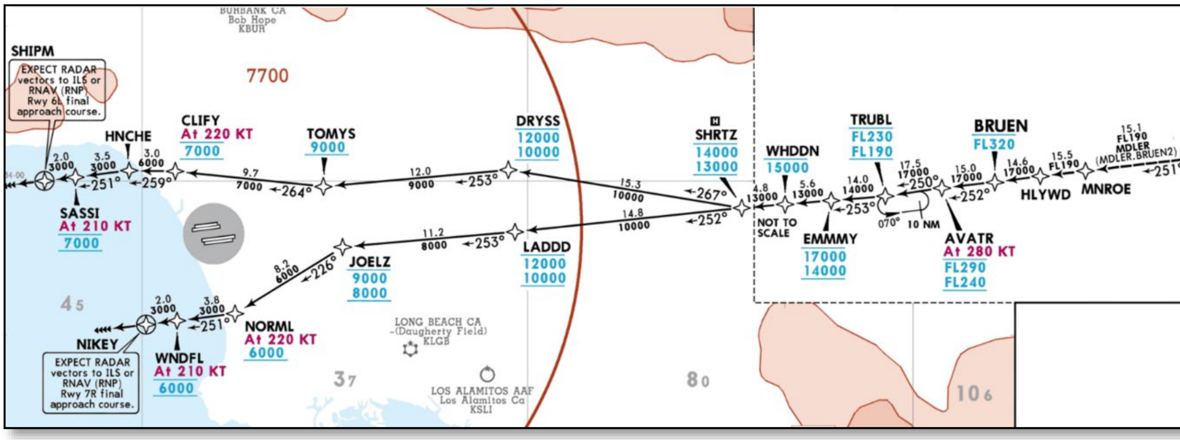


Figure 5. Excerpt from arrival procedure (Appendix D RNAV Arrival – BRUEN2) showing waypoints and constraints for reference for Scenario 6.

Scenario 6 resumed near MNROE, top of descent occurred near HLYWD, and participants received the request to slow to 250 knots at BRUEN. Participants should resume published speeds after JOELZ, meaning they should cross NORML at 220 knots.

Scenario 6 assessed the cognitive skills and knowledge needed for planning and controlling airspeed, altitude, thrust, and trajectory during arrival descent, including air traffic control interventions that affect flightpath management (FPM). In this scenario, the flight management system (FMS) built a geometric profile based on a predicted flightpath of the area navigation (RNAV) arrival. ATC issued a speed constraint at the beginning of the arrival. This can result in a mismatch between the FMS geometric profile and what is needed during the flight segment to adhere to constraints. The outcome may be a shallower flightpath, potentially impacting conformance to published altitude restrictions. A tailwind further affected the flightpath and meeting published restrictions.

Participants should use knowledge of aircraft systems and aircraft performance with information about the arrival such as where the aircraft currently is on the arrival to decide how to adhere to the ATC speed constraint. For example, the aircraft is expected to be in managed descent at the beginning of the scenario. Participants should use knowledge with cognitive skills to decide whether they use selected speed to adhere to the speed constraint or if they enter the speed constraint into the FMS. Participants should then collect and integrate information from the PFD, ND, FMS, and EFB about upcoming constraints and the current aircraft energy state, such as current airspeed, current altitude, and vertical deviation from the path. Applying knowledge such as the 3:1 heuristic and knowledge of aircraft systems and aircraft performance, participants should estimate, predict, and plan their energy management strategy and compensatory adjustments to pitch and rate of descent to ensure the aircraft will meet constraints.

Scenario 7: Navigation Source Transition during Arrival-to-Approach Operations
Scenario 7 started with the aircraft over the NIKEY waypoint at the end of the RNAV arrival as participants were transitioning to receiving vectors from ATC. This scenario flowed from Scenario 6 with no interruption. As participants crossed NIKEY, Southern California (SOCAL) TRACON provided vectors to the participants, beginning with "descend and maintain 3000 ft." Approximately 7.5 miles after NIKEY, SOCAL issued "turn right heading 340, slow to 180 knots." When the aircraft was 2.5 miles from the final approach course, SOCAL issued "turn right heading 040, maintain 2000 until established on the localizer, cleared ILS runway 7 right." Two miles from FUMBL, the final approach fix, SOCAL handed the aircraft over to Los Angeles Tower. The scenario ended when the aircraft landed and came to a complete stop on the runway. Participants were instructed to bring the aircraft to a complete stop in the initial briefing.

The goal of this scenario was to assess cognitive skills and knowledge for planning and controlling airspeed, altitude, thrust, and trajectory during a normal ILS approach. The scenario included transitioning from an RNAV arrival to vectors to an ILS approach. Participants should use the cognitive skills of information collection, integration, estimation, prediction, planning, and communication with knowledge to execute a smooth transition from the arrival to the approach and landing. For example, participants should know how and when to arm the approach. Participants should use knowledge of autoflight systems, aircraft performance, and FMS interactions with the skills of information collection, integration, and communication to control airspeed, altitude, and heading in response to ATC. Participants should apply knowledge regarding autoflight systems, FMS interactions, and aircraft performance such as v-speeds, they should collect and integrate information from the PFD, and they should use estimation and communication to configure the aircraft appropriately for landing.

Modifications to Design for Longitudinal Study

A Longitudinal Study compared a pilot's skill and knowledge from the Cross-Sectional Study to their skill and knowledge five months later. Six A320 pilots and five B737 pilots who participated in the Cross-Sectional Study came back to participate in a follow-on evaluation. Degradation within-subjects was explored, and insights provided additional support for skill degradation over time.

The experimental design was the same as the Cross-Sectional Study, with minor modifications. Expectations placed on participants did not change from the first to second evaluation. Modifications to the scenarios were needed, however, in order to mitigate two risks: (1) risk that participants who exhibited lack of proficiency in the Cross-Sectional Study would recall where they had gaps and strive to close those gaps when returning, and (2) risk that they would remember cognitive triggers from the Cross-Sectional Study and respond exactly the same way without exercising any cognitive skill. Flying the same route is typical for many Part 121 pilots. However, flying exactly the same route with exactly the same requests would likely cause the participants to try to recall their previous experience. In addition, any participants who recognized their lapse in skill in the first study may have had an emotional response to this lapse, leading them to hold on the memory of the events in the study. Modifications were kept to a minimum to mitigate risk that any change in skills observed from the Cross-Sectional Study were due to differences in the scenarios and not changes from the baseline collected during the Cross-Sectional Study. The verbal protocol was modified only in so far as updates were needed to align with scenario modifications. The updated flight release, charts, and ATC instructions can be found in Appendix K – Longitudinal Study - Flight Releases, Appendix L – Longitudinal Study - Charts, and Appendix M – Longitudinal Study - ATC.

Scenario 1: Flight Plan Review and Assessment
No modifications were made to Scenario 1 for the Longitudinal Study.

Scenario 2: Pre-flight Preparations and Flight Deck Setup
No modifications were made to Scenario 2 for the Longitudinal Study.

Scenario 3: Area Navigation (RNAV) Departure from Phoenix (KPHX)
No modifications were made to Scenario 3 for the Longitudinal Study.

Scenario 4: Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude
The update to Scenario 4, which involved assessing tradeoffs between speed and vertical flightpath during climb at a high altitude, preserved the same math problem with different variables. This enabled evaluation of the execution of the same exact cognitive skills and cognitive processes while mitigating the risk of exact recall. In order to preserve the math problem, ATC requested at FL260 that the participant make it FL320 in three minutes or less. In the Cross-Sectional Study, ATC requested at FL280 that the participant make it to FL320 in two minutes or less. This required the participant to leverage cognitive skills to identify if they

could meet the request. In the first scenario, the participant must perform the following math to determine their optimal rate of climb: (FL320 - FL280) feet / 2 minutes = 4000 feet / 2 minutes = 2000 feet per minute. The updated verbiage required the participant to perform the same math problem with different variables: (FL320 - FL260) feet / 3 minutes = 5000 feet / 3 minutes = 1666 feet per minute.

Scenario 5: Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise

This scenario focused on managing fuel and the effects of fuel burn on the flightpath. Study participants utilized cognitive skills with knowledge to decide if they could hold for as long as requested or if they should divert to the alternate. This included calculating the fuel burn to get to their alternate, deciding on a minimum fuel with which they were comfortable, and exploring options in the surrounding area. The modification to this scenario was to change the alternate from San Francisco to San Jose. This small change resulted in slightly different fuel requirements, which participants then considered in their decision-making.

Scenario 6: Energy Management during RNAV Arrival Descent to Los Angeles (KLAX)

The update to Scenario 6 preserved the effect on the flightpath from the Cross-Sectional Study. In the Cross-Sectional Study, ATC issued a speed constraint resulting in a mismatch between the FMS geometric profile and what was needed during the flight segment. In the update, ATC still issued a speed constraint, but verbiage and delivery was modified as shown in Table 10 to reduce similarity to the Cross-Sectional Study.

Table 10. ATC verbiage in Scenario 6 for Cross-Sectional Study and the Longitudinal Study.

Cross-Sectional Study	Longitudinal Study
At Top of Descent (TOD): ATC: *MAC689 descend via the BRUEN2 for Rwy 7R, altimeter 29.99.*	At Top of Descent (TOD): ATC: *MAC689 descend via the BRUEN2 for Rwy 7R, altimeter 29.99. Best forward speed to BRUEN.*
As aircraft crosses BRUEN: ATC: *MAC689 LA Center contact SoCal approach on 124.0* Pilot: *Checks in* ATC: *MAC689, SoCal approach, expect ILS runway 7R. After AVATR, maintain 250 knots until JOELZ. Resume published speeds at NORML.*	As aircraft crosses BRUEN: ATC: *MAC689 Los Angeles Center contact SoCal approach on 124.0* Pilot: *Checks in* ATC: *MAC689, SoCal approach, expect ILS runway 6L.* Aircraft is 10 nautical miles (NM) from AVATR: ATC: *MAC689 slow to 250 K indicated airspeed (IAS), resume published speeds at DRYSS.*

Scenario 7: Navigation Source Transition during Arrival-to-Approach Operations

The update to Scenario 7 changed the runway from 7R to 6L. Runway 6L is parallel to 7L. The approach is still a normal ILS approach, with vectors being provided to land runway 6L versus runway 7R.

The A320 Flight Training Device (FTD) simulator and Boeing 737NG research-based simulator were used in the Longitudinal Study. Audio, video, log data, and verbal protocol data were collected; the data analysis approach was the same.

Experimental Protocol

Upon arriving, participants were directed to a briefing room where they first signed a consent form. They then received an overview of the study describing at a high-level what they would be doing and experiencing that day as well as a safety briefing for the scenario. Participants were provided with the EFB they would be using and given a short familiarization with it. The first scenario was then conducted in the briefing room. An experimenter provided instructions and information about the status of the aircraft to the participants at the beginning of each scenario. To capture the pilot's retrospective perspective after each scenario, the experimenter executed a verbal protocol where participants were asked to verbalize their thoughts, reasoning, decision-making, and actions while or immediately after the scenarios (see Measures and Data Analysis*)*. The experimental protocol can be found in Appendix B – Experimental Protocol.

After the verbal protocol was conducted for the first scenario, the participant was escorted to the simulator and scenarios two through seven were conducted in the simulator. After completing the verbal protocol for the seventh scenario, the participant was escorted back to the briefing room for a short debrief and final questionnaire to capture their demographics (Appendix G – Demographics Questionnaire). During each scenario, a qualified pilot played the role of the ATC. The ATC instructions can be found in the Appendix E – ATC. All participants acted as the PF in all scenarios. The role of PM was filled by a confederate pilot qualified in the aircraft type. The PF sat in the left seat while the PM sat in the right seat. The following section describes the design of the scenarios intended to elicit cognitive skills and knowledge.

Participants

In this study, degradation was assessed primarily by comparing groups of participants. Three groups were recruited: (1) individuals who meet requirements as defined in 14 CFR 121.439 pilot qualification for recent experience[4], (2) individuals who used to qualify for recent experience in either an A320 or B737, but whose last flight in one of those aircraft was 6-12 months in the past, or (3) individuals who used to qualify as recent in either an A320 or B737, but whose last flight in one of those aircraft was 12 – 24 months in the past. Participants were recruited through prior participant connections, with the help of a professional recruiter, and through social media connections. The majority of participants for each aircraft type came from the same operator to control for potential variability in task execution due to differences between operators. All pilots recruited were either type rated on the A320 or the B737, or they had been type rated on the B737 or A320, it was the last aircraft they flew, and they had not flown a Part 121 operations since they last flew the A320 or B737. All participants were male. Average age and flight hours are provided in Table 11. Given the small sample size, attempts were made to reduce variability in age and hours as much as possible. Eleven of the A320 pilots had more than 10,000 hours of experience. Ten of the B737 pilots had more than 10,000 hours of experience.

Table 11. Average age and flight hours by participant group and aircraft type.

Aircraft Type (n = 12 per type)	**Participant Group (n = 4 per group)**	**Age**		**Flight Hours**	
		M	*SD*	*M*	*SD*
A320 Participants	Met requirements for recent experience	57.8	12.6	17,987	10876
	Away from flying 6-12 months	65.3	.4	25,820	6841
	Away from flying 12-24 months	65.5	.5	24,625	8727
B737 Participants	Met requirements for recent experience	48.3	3.9	13,025	5556
	Away from flying 6-12 months	60.0	10.0	22,375	8557
	Away from flying 12-24 months	64.8	3.8	23,129	7371

Met requirements for recent experience was based on requirements as defined in 14 CFR 121.439 pilot qualification for recent experience, "Away from flying 6-12 months" refers to pilots who used to qualify for recent experience in either an A320 or B737 but have not flown for 6 – 12 months, "Away from flying 12-24 months" refers to pilots who used to qualify for recent experience in either an A320 or B737, but have not flown for 12 – 24 months.

[4] 14 CFR § 121.439 Pilot qualification: Recent experience - https://www.ecfr.gov/current/title-14/chapter-I/subchapter-G/part-121

Of the 12 A320 pilots, two were First Officers (FO). One of the FOs was current, and one was inactive for 6-12 months. Of the 12 B737 pilots, two were FOs. Similarly, one of the FOs was current and one inactive for 6-12 months. The other ten participants for both aircraft types were Captains. Shown in Table 12, the most common number of type ratings for the A320 pilots was four, while the most common number of type ratings for the B737 pilots was three. In addition to having an Airline Transport Pilot (ATP) certificate, other ratings included glider, rotorcraft, Certificated Flight Instructor (CFI), and Certificated Flight Instructor Instrument (CFII). Six of the 12 A320 pilots flew general aviation, and five of the 12 B737 pilots flew general aviation. One of the A320 pilots and one of the B737 pilots were military pilots in the reserves. None of the A320 pilots were check pilots; five of the 12 B737 pilots were check pilots.

Table 12. Pilots from each aircraft type with different ratings, other operations (ops), and experience.

Ratings	A320	B737
One to two	1	5
Three-Four	5	6
Five or more	3	1

Other Ops/Experience	A320	B737
GA	6	5
Military	1	2
Check pilot	0	5

Longitudinal Study Participants

Individuals who participated in the Cross-Sectional Study were recruited to participate in the Longitudinal Study. All individuals who returned for the Longitudinal Study had not been active in Part 121 operations for an additional five months. Six individuals returned to participate in the A320, and five individuals returned to participate in the B737. Of those who returned whose last flight had been in the A320, the additional five months away meant one participant remained in the 6-12 month group, four participants had been away from flying for 12 – 24 months, and one participant had been away from flying for more than 24 months. Of those who returned whose last flight had been in the B737, the additional five months away meant four participants had been away from flying for 12-24 months and one participant had been away from flying for more than 24 months.

Simulators

Two simulators were used in the study: an Airbus 320 simulator and a Boeing 737NG simulator. The Airbus simulator is a flight training device, and has the potential for motion, while the Boeing 737NG simulator is a research-based simulator and has a fixed-base. For consistency, motion was not enabled in the A320 simulator. Each simulator is described in more detail below.

A320 Flight Training Device (FTD)

The A320 portion of the study was conducted at the FAA's Flight Operations Simulation Laboratory at the Mike Monroney Aeronautical Center in Oklahoma City. The team used an A320 flight training device (FTD) without motion (Figure 6). The simulator is an A330 level D equivalent. For the purpose of research, the Future Flight Technologies Branch within the Flight Technologies and Procedures Division of the FAA (AFS-430) has an A320 aerodynamics package which can convert simulator performance to that of an A320. This allows the simulator to have similar performance and handling characteristics of an A320, but flight deck size and layout still represents an A330. The A330 flight deck is similar to the A320 flight deck with the most notable difference being in terms of size, and for the purposes of this study, this was determined to be adequate.

Figure 6. A320 simulator located at the Mike Monroney Aeronautical Center.

B737NG Research-Based Simulator

The B737NG portion of the study was conducted on a research-focused, fixed-base 737NG-800 flight simulator in the Honeywell Deer Valley facility (Figure 7). The simulator is equipped with fully functional displays and control interfaces. Three 55' LCDs driven by TripleHead2Go (Matrox Electronic Systems Ltd, Dorval, Quebec) provide an out-the-window view. The simulator is a dual seat training device equipped with stick shaker yokes, linked adjustable rudder pedals, motorized throttle quadrant, an autopilot mode control panel (MCP), dual control display unit (CDU)s, and dual PFD/ND displays. The Dual FMS includes flight planning capabilities, VNAV/LNAV, autothrottles, audio functions, and accurate displays.

Figure 7. B737NG simulator located at the Deer Valley Honeywell facility.

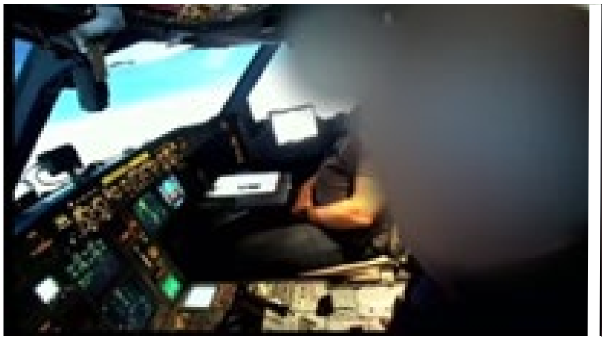
Data Collection

For this work, a verbal protocol was used to collect data pertaining to pilot thought processes and reasoning. A verbal protocol is a research method used to capture and analyze the thought processes and cognitive activities of individuals as they perform a task. In verbal protocol analysis, participants are asked to verbalize their thoughts, reasoning, decision-making, and actions while or immediately after they engage in a specific activity. This method is particularly useful in understanding complex cognitive processes (Chi et al., 1994). The verbal protocol was developed based on the design of the scenarios and the cognitive skills inventory. The probes were refined using a think-aloud approach with two SME pilots with Part 121/Part 135 experience. The questions posed to participants can be found in Appendix B – Experimental Protocol.

Video and audio was recorded in order to capture the verbal protocol data. In addition, simulator data and subjective metrics of workload were also collected from the participants in each scenario. Video data, shown in Figure 8 and Figure 9 captured the following:

- Left and right side seat views of pilot participant
- Front view of participant capturing facial expressions
- Participant’s flight management computer (FMC)
- Participant’s primary flight display (PFD)
- Participant’s The navigation display (ND)
- Wide angle view of the flight deck
- (A320 only) Close-up view of flight control unit
- (B737 only) Detailed capture of FMC

For the A320, the overall view did not provide enough detail of the flight control unit so extra video was captured of that system. For the B737, the quality of the video capturing the physical FMC was low, so extra video was captured of that system.

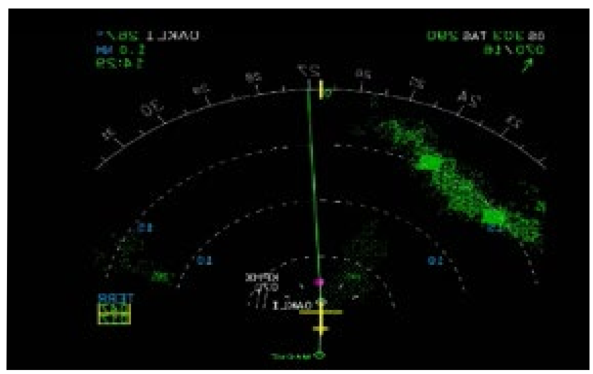

(a) Left seat side view of pilot actions


(b) Right seat side view of pilot actions.


(c) Front view capturing facial expressions

(d) Participant's flight management computer

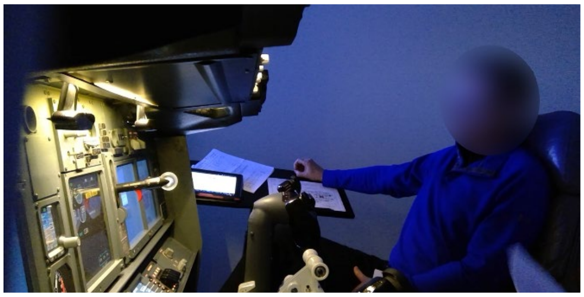
(e) Participant's primary flight display

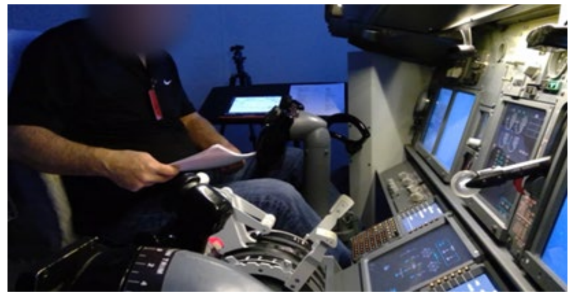

(f) Participant's navigation display

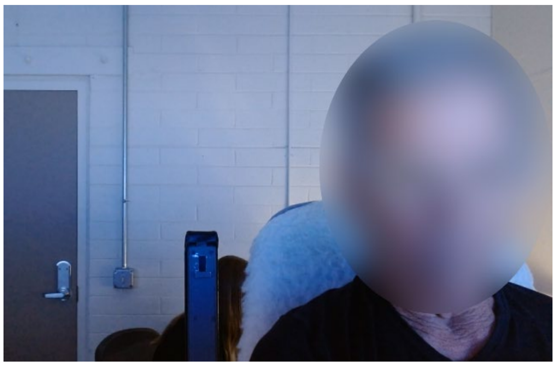

(g) Wide angle view of flight deck

(h) Close-up view of flight control unit

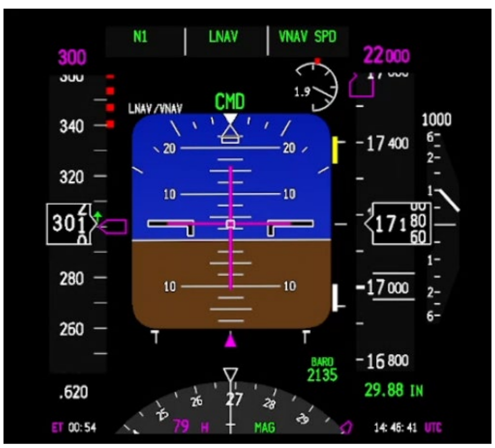
Figure 8. Sample images of the video captured in the A320 simulator.


(a) Left seat view of pilot actions


(b) Right seat view of pilot actions.


(c) Front view capturing facial expressions

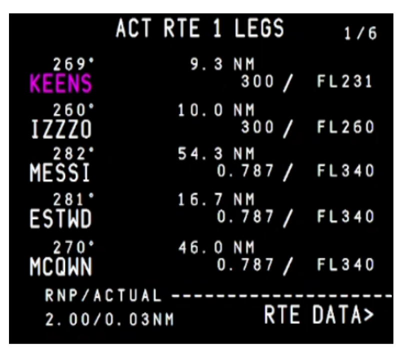

(d) Participant flight management computer



(e) Participant’s primary flight display

(f) Participant’s navigation display


(g) Wide angle view of flight deck



(h) Detailed capture of FMC

Figure 9. Sample images of the video captured in the B737 simulator.

Audio was captured using multiple microphone systems for redundancy and included an imbedded audio recording system (for the A330 simulator), a Razer Seiren V3 microphone (Razer Inc., Irvine, CA) connected to a laptop, and two built-in microphones of the C920 HD PRO Webcam (Logitech International S.A., Lausanne, Switzerland). Audio captured verbalizations by the participant, experimenter, and confederate pilot monitoring. The simulator data included recorded aircraft parameters such as latitude, longitude, heading, indicated airspeed, rate of climb, above ground level (AGL) altitude, and mean sea level (MSL) altitude for modeling the participant's flightpath. A modified version of the NASA Task Load Index (TLX; Hart & Staveland, 1988) referred to as the Raw TLX (RTLX) (Hart, 2006) and consisting of six dimensions on a shifted scale was used to assess workload. The six dimensions include mental demand, physical demand, temporal demand, performance, effort, and frustration, measured on 7-point Likert scale.

The audio data was recorded in the file form of MP4 or MKV. These were converted to .WAV file format. WhisperX (Bian et al., 2023) was used for local-device audio transcription using Visual Studio (1.90.1, Microsoft) 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 (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. Together with the video and simulator data, the transcriptions were used to identify the participants' behavior, actions, and decisions during the scenarios (concurrent data) and their verbal responses to a verbal protocol (retrospective data).

The simulator flight data, de-identified demographics, responses to workload, and experimenter notes and observations were documented and transferred to the FAA after the conclusion of the data collection on December 19, 2023. The Data Management Plan can be found in Appendix P – Data Management Plan. Audio, video, and transcripts were not transferred to the FAA as this data was not de-identified.

Measures and Data Analysis

Several different kinds of data were collected, and this allowed for several different measures and analyses to be performed to explore degradation from different perspectives. Each measure and how that measure was assessed is described below.

Verbal Analysis

The verbal analysis method was used to assess the verbal protocol for cognitive skills and representation of knowledge that pilots have and how that representation may degrade over time. The verbal analysis method focuses on verbalizations to capture the knowledge that might underlie those verbalizations (Chi, 1997). Although measures such as response times and errors can uncover the representation of knowledge, analyzing verbal data can provide a much richer, more detailed, and perhaps more accurate representation of knowledge. Verbal analysis can help reveal the mental model that an individual possesses without necessarily creating an ideal template of that mental model a priori. This is important because the focus in this work is on differences between-groups and within-individuals to assess degradation.

Once the verbal protocols have been transcribed, the verbal analysis method consists of eight steps:

1. Reducing or sampling verbal protocols (for feasibility of analysis).
2. Segmenting the reduced or sampled protocols (e.g., at the level of the utterance)
3. Developing or choosing a coding scheme or formalism.

4. Operationalizing evidence in the coded protocols that constitutes a mapping to some chosen formalism.
5. Depicting the mapped formalism.
6. Seeking pattern(s) in the mapped formalism.
7. Interpreting the pattern(s).
8. Repeating the whole process, perhaps coding at a different grain size (optional – not done here).

The verbal protocols collected in this work contain substantial data with insight into many potential areas of research. To focus the analysis on degradation of cognitive skills and knowledge, the protocols were manually reviewed for responses that were pertinent to the cognitive skills and knowledge needed for flightpath management. A coarser grain size consisting of responses to the probe questions was used for the unit of analysis. Future work should consider analysis at a different grain size.

The coding scheme was based on the cognitive skills inventory and was specific to the knowledge required in each scenario. In each scenario, pilots need to build a mental model of the flightpath using declarative knowledge, procedural knowledge, abstract knowledge, and cognitive skills. The coding scheme initially focused on coding for evidence of the cognitive skills collection, integration, estimation, prediction, planning, and communication (see Table 13) as well as evidence of FPM knowledge as defined in the inventory (see Section "FPM Knowledge). The coding scheme was refined to include subcodes for each skill based on initial coding attempts, emerging insights from the data, and alignment between two coders. For example, what system and information was collected or integrated; for communication, subcodes based on work by Ligda et al. (2015) and Orasanu (1994) were used to further define what and how pilots were communicating. These included communication requests for assistance from the PM, clarifications or requests to repeat information, communications emphasizing a weakened mental model (e.g., "isn't that strange? You forget where the flight director is" or "little shaky takeoff there"), social communications (e.g., "how long have you been flying for?"), or communications to establish a shared understanding of the flightpath or aircraft systems.

Table 13. Coding scheme for cognitive skills and knowledge.

Skill	Description	Example
Collection	Participant looked for, sought, and/or identified information needed for flightpath management (FPM) (e.g., planning, executing, or assuring the guidance and control of aircraft trajectory and energy, in flight or on the ground.) This includes from systems (EFB, PFD, ND, FMS, etc.) and people (PM, ATC, Dispatch).	Collecting vertical flightpath and speed information during climb: *"I'm just watching the altitude in the climb and the vertical speed in the climb"* Collecting vertical flightpath information during arrival: *"I was looking at the green dot* [referring to vertical flightpath indicator on altitude tape] *because that's the plan, the optimum flightpath."* Collecting information on restriction during arrival: *"Well, obviously the altitude strip, but I was checking the restriction to make sure it was in there, which it was."* Collecting speed and altitude during approach: *"Especially IMC when you get low there, I was just backing it up with this [pointed to standby instruments]. My eyesight's not good enough to always see that one there."*

Integration	Participant combined multiple pieces of information towards an idea, concept, solution, which was needed for FPM.	Integrating information to perform fuel calculation: *"I calculated how much we would need to LA, from LA to our alternate, plus a certain amount for me, and then I'd put all those together and contact dispatch"* Integrating information to validate meeting crossing restriction: *"I cross checked vertical speed and the climb was a positive rate with the airspeed, and they all correlated with the flight directors so I was happy"*
Estimation	Participant forms judgements of when airplane might get to next fix or waypoint, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.	Estimating needed rate of climb: *"Well, I would have probably, in that case, now you're going 6,000 feet in five minutes. You'll probably have to do better than 1000 foot a minute to do it."* Estimating meeting constraint: *"I knew we were going to make it [next constraint] because I could see where we were and what was coming up"* Estimating distance to takeoff: *"I knew that it was going to be a longer takeoff roll"*
Prediction	Participant anticipates future events relevant to FPM.	Predicting effects of slowing during arrival on flightpath: *"I should say when the clearance came to maintain 250 until JOELZ and then we were at JOELZ… realized okay now we're going to have another issue"* Predicting effects of slowing during arrival on flightpath: *"When we passed JOELZ, I thought it [the aircraft] would go to 250 for a bit, then come down but it didn't"*
Planning	Participants draft a strategy, approach, and/or a set of actions or tasks to be accomplished in the future to address FPM.	Developing plan for holding: *"We'll do a couple turns in holding and if not, we'll divert to SFO."* Planning to manage effects of slowing on flightpath: *"I had to plan ahead so that I didn't have to go in and out [of using speed brakes]."* Planning when to brief: *"It's a short flight so we'll brief the arrival as soon as we get up there [to FL340]"*
Communication	Participants share (or indicate they would share) or request information with PM / ATC / dispatch / cabin crew about the flightpath, their understanding of the flightpath, or managing the flightpath. Participants share (or indicate they would share) or request information with PM / ATC / dispatch / cabin crew to establishing shared understanding of the flightpath.	Communicating about operational approach to making crossing restriction: *"You cool with me doing it this way?"* Communicating to FO about making crossing restriction: *"I'd talk to the FO and say yeah I think we're not going to have a problem making that clearance. Do you agree?"* Making callouts: *"Just making an announcement that the airplane's doing what it's supposed be doing"*

The verbal protocol was recorded with audio and video; video data was used to supplement coding of the verbal protocols when participant answers involved gestures or references to the flight deck environment. The video data was then also coded for the cognitive skills exhibited during the execution of the scenarios (versus during the verbal protocol) in the same manner as the verbal protocols. Three individuals were involved in the coding process, two researchers with experience in qualitative coding and a pilot with 2500 flight hours. Interrater agreement was calculated as [agreements / (agreements + disagreements) × 100%], and agreement was 88.8%. Discrepancies between coders were resolved through review.

Once the data had been coded, the data was then reviewed and graphically represented with drawings of connections between knowledge components and skills to visualize and derive the mental models' individual participants were verbalizing in different scenarios. This enabled better cross-comparison between participants and participant groups to understand and visualize potential degradation.

Flightpath Visualizations

Recorded aircraft parameters including latitude (degrees), longitude (degrees), indicated airspeed (IAS) (knots), rate of climb (feet per minute), above ground level (AGL) altitude (feet), and mean sea level (MSL) altitude (feet) were used to visualize participants' flightpaths. Visualizing a participant's flightpath can provide evidence of the implications of gaps in cognitive skills and knowledge. Gaps in cognitive skills and knowledge were identified in the verbal analysis, and participants flightpaths then examined for implications. For example, if a participant exhibits gaps in their ability to recall specific knowledge, such as when and where to enable the flight director, this gap may have implications for their ability to manage their airspeed, altitude, and climb rate during takeoff. This gap would be identified in the verbal protocol and then potentially be reflected in the visualization of their flightpath.

Unfortunately, the B737 data for some scenarios was corrupted and/or did not produce adequate visualizations. The video data was used to examine the B737 participants' flightpath data when the simulator data was insufficient. For some scenarios in the results, graphs may only be shown for the A320 participants due to this data collection issue.

Time on Task

Time on task can be an indicator of knowledge and cognitive skill execution and potentially degradation (Ackerman, 1988). Time on task was assessed for the flight plan review, preflight briefing, flight deck setup, and the approach briefing. These four tasks are thought to have downstream effects on flightpath management (Holder, Finseth, & Lubold, 2021), given their importance in building a mental model of expectations regarding the planned route and all the factors that may impact it, including weather, winds, traffic, aircraft weight, fuel, maintenance status of the aircraft, the capabilities of the aircraft, and other information like NOTAMs and applying local knowledge of the departure and arrival airports.

The time for executing each of these tasks was captured through manually coding the videos of the scenarios. The time on task was compared using one-way analysis of variance (ANOVA), with group as the factor and time on task as the dependent variable. Pairwise comparisons were conducted with a pairwise t-test, and acceptance level was adjusted to control for type I errors (Bonferroni adjustment). Results were considered significant at $p < .05$. Effect sizes are reported with eta squared (η_p^2) where $\eta_p^2 = 0.01$ is considered a small effect size, $\eta_p^2 = 0.06$ a medium effect size, and $\eta_p^2 = 0.14$ is considered a large effect size (Perugini, Gallucci, & Costantini, 2018); effect sizes are corrected for Greenhouse-Geisser if needed (Lakens, 2013).

Workload Assessment

To assess and control for potential differences due to workload, a modified version of the NASA TLX was used. Referred to as the Raw TLX (RTLX), this version eliminates the weighting process and shifts the subscales (Hart, 2006). Ratings were captured for each scenario. Repeated measure analysis of variance

(RM-ANOVA) was used to assess group differences, with participant ID as a random factor and average workload as the dependent variable. Sphericity violations used Greenhouse-Geisser corrections. Pairwise comparisons was conducted with pairwise t-test, and acceptance level was adjusted to control for type I errors (Bonferroni adjustment). Results were considered significant at $p < .05$. Effect sizes are reported with eta squared (η_p^2) where $\eta_p^2 = 0.01$ is considered a small effect size, $\eta_p^2 = 0.06$ as medium, and $\eta_p^2 = 0.14$ is considered a large effect size; effect sizes are corrected for Greenhouse-Geisser if needed (Lakens, 2013).

Note on Power Analysis

The results of this work focus primarily on the qualitative, verbal analysis. Quantitative analyses performed was performed on the workload measures and time on task. An a priori power-analysis conducted using G*Power version 3.1.9.7 (Faul et al., 2007) indicated that a sample size of 32 pilots would be needed to measure an effect size of $\eta_p^2 = 0.5$ (small to medium) with an $\alpha = .05$ and 80% power (Cohen, 1988). With 24 pilots, the quantitative results are reported but underpowered. The risk of Type II error is moderate, and therefore the statistical analysis is secondary to the trends observed in the qualitative data.

5. RESULTS

Scenario 1: Flight Plan Review and Assessment

In this scenario, participants used knowledge and cognitive skills to review information in the aeronautical charts and flight release such as the route, alternate, Phoenix ATIS, METARs, fuel loading, weight, passenger loading, NOTAMs, and MEL items. The verbal protocol elicited the understanding and expectations participants developed from their review and the knowledge participants used to review the release. Differences between participants' understanding and expectations of the flight, and the knowledge they used are described below.

Scenario 1 Cross-Sectional Results

The flight release contains a breakdown of the fuel for the flight. Participants were asked "How did you determine if the information a dispatcher provided in this flight release is an accurate reflection of what is needed to complete the flight from a fuel perspective?" The majority of the participants were able to immediately answer this question. These individuals indicated the "Destination" fuel, "Final Reserve," "Total Fuel," and/or other categories in the fuel breakdown in the release, and they described having a heuristic for fuel burn (e.g., such as 6,000 pounds per hour for the A320), and they used this heuristic in combination with information regarding the length of the flight and the intended alternate to estimate whether they had enough fuel. Several participants had to go back and look at the release. These individuals acknowledged that they did not actually look at the fuel. They also tended to state that they trust dispatch. Two 12-24 month participants based their assessment on different heuristics than the other pilots and admitted that they did not fully recall what they used to use and so were being conservative in their estimation. This suggests that this knowledge may be susceptible to degradation over time.

Participants were provided with a long list of NOTAMs. Participants either thoroughly reviewed the NOTAMs in-depth, making notes of any they felt could be relevant, quickly scanned and mentally noted any potentially relevant NOTAMs, or they did not review the NOTAMs. When participants were asked about whether there were any NOTAMs that were applicable to the flight or which might impact the flight, participants who had not reviewed the NOTAMs acknowledged they had not reviewed them and tended to state that anything that was applicable to the flight would also be found in the ATIS, therefore they did not feel the need to review the NOTAMs. There was not a clear difference between pilot currency and participant likelihood to review the NOTAMs. Differences in participant review and use of the NOTAMs was not a result of being away from flying.

The flight release contained weather for Phoenix, Los Angeles, and San Francisco, which was designated as the alternate. Participants were asked how they assess weather and about their knowledge of aircraft performance. Some participants noted that it was a hot day in Phoenix (temperature was 35° Celsius), and they checked the runway length and performance numbers (e.g., flex temperature or assumed temperature settings) accordingly. They leveraged knowledge of the performance characteristics of the A320 or B737 to perform this check. Other participants did not collect information about the temperature, and when asked, needed to look and consult the release. Some of these participants neglected collection of this information because they forgot to do it; some appeared reliant on their familiarity of the aircraft, airport, and other skills, and did not feel the need to actively perform this assessment. Similar to the review of NOTAMs, there was not a clear difference between pilot currency and participant assessment of weather or knowledge.

All participants had experience with Phoenix and Los Angeles and had local knowledge of the two airports. 21 of 24 participants (11 B737 and 10 A320 pilots) commented that landing east in KLAX was unfamiliar to them. Only three participants had familiarity with landing east. None of the participants were familiar with the BRUEN2 arrival. Six participants mentioned that it was very common for ATC at KLAX to request aircraft to slow and to keep aircraft high, and that they had this in mind as they reviewed the flight. This knowledge did not differ by participant group.

Reviewing the flight release involves collecting information such as fuel and weather, integrating that information to develop a mental picture of the flight, performing estimations to assess if the plan for the flight checks out, making predictions such as the likelihood of going to an alternate, and planning accordingly. Executing this review can take time. Comparing how long it took different pilots to review the release may be a potential indicator of degradation, though other factors such as depth of review and individual differences also play a role. The average time it took for pilots to review the flight release is shown in Figure 10 and Figure 11**.** For the A320 pilots, 6-12 month pilots took the longest to review the release and aeronautical charts at an average of 16.93 minutes (*SD* = 6.5), versus current pilots at 11.58 minutes (*SD* = 9.5) and the 12-24 month pilots at 10.00 minutes (*SD* = 7.6). For the B737 pilot group, the 12-24 month pilots took the longest to review the flight plan at 17.19 minutes (*SD* = 14.9), versus current pilots at 5.40 minutes (*SD* = 1.9) and 6-12 month pilots at 8.75 minutes (*SD* = 3.4). Differences in time to review were not statistically significant for the A320 pilots, $F(2, 9) = 0.84$, $p = .46$, $\eta_p^2 = 0.16$, or the B737 pilots, $F(2, 9) = 1.88$, $p = 2.08$, $\eta_p^2 = 0.29$. This lack of significance implies that time to review the flight release may not be a strong indicator of degradation on its own and should be considered with other factors.

Cross-Sectional Study findings based on 12 A320 participants reviewing a flight release for a flight from Phoenix (KPHX) to Los Angeles (KLAX)

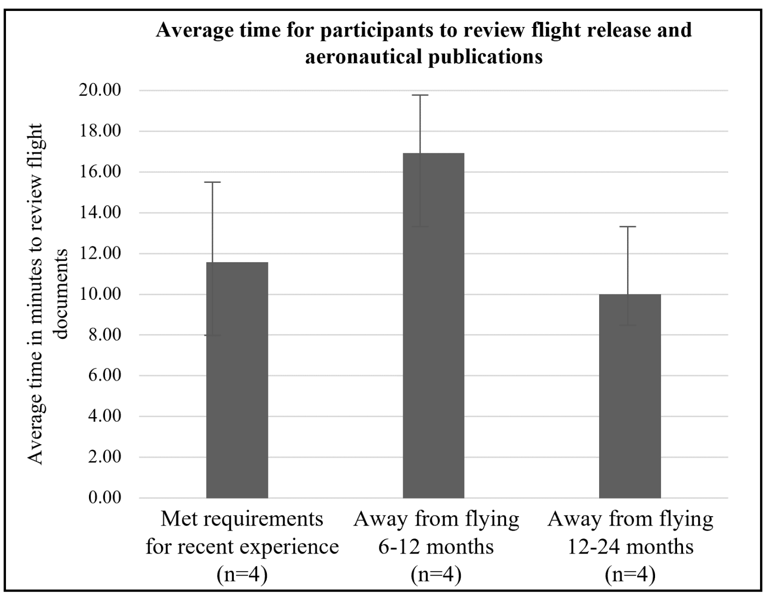


Figure 10. Average time for A320 participants to review flight release and aeronautical publications.

Cross-Sectional Study findings based on 12 B737 participants reviewing a flight release for a flight from Phoenix (KPHX) to Los Angeles (KLAX)

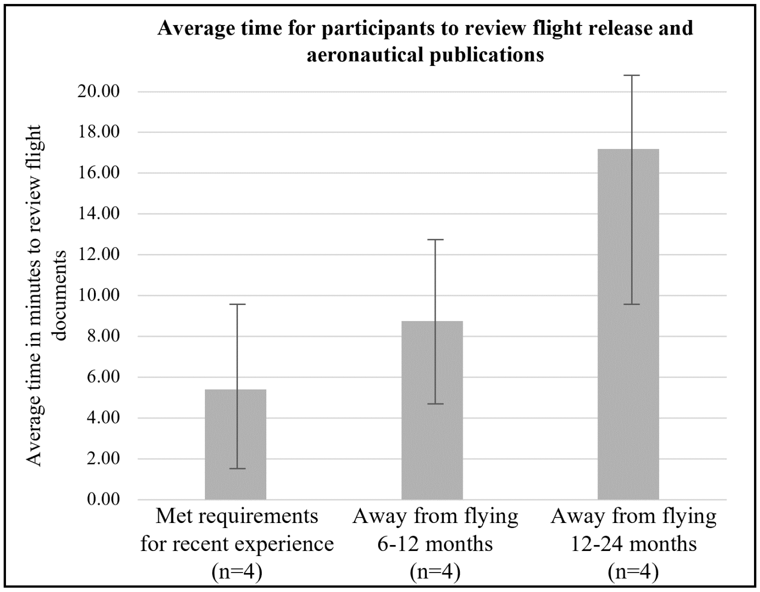


Figure 11. Average time for B737 participants to review flight release and aeronautical publications.

The time to review the release differed between the A320 and B737 pilots. For example, the current B737 pilots took on average 5.40 minutes to review the release and the current A320 pilots took 11.58 minutes. The current B737 pilots were all very familiar with interacting with paper releases, while the current A320 pilots were more accustomed to electronic releases. This may be one explanation for why there is an observable difference between these two groups of current pilots. Information collected could be another explanation (e.g., current A320 pilots spent longer reviewing NOTAMs); however, this did not appear to be the case.

Scenario 1 Longitudinal Results

In comparison from the Cross-Sectional Study to the Longitudinal Study, there were two pilots who had challenges recalling exact heuristics for fuel and weight that they did not have challenges recalling in the Cross-Sectional Study evaluation. Both participants were approaching more than 24 months away from flying, and they were able to still assess what was necessary; however, their challenge with recall supports the results from the Cross-Sectional Study that this kind of detailed knowledge is susceptible to degradation.

From the Cross-Sectional Study to the Longitudinal Study, all pilots who returned still exhibited the same local knowledge regarding Phoenix and Los Angeles that they had expressed during the Cross-Sectional Study (e.g., regarding terrain, traffic patterns, and weather). In addition, participants responded similarly in the Longitudinal Study as they did during the initial evaluation with regard to NOTAMs. If they did not review NOTAMs in the Cross-Sectional Study, they did not review NOTAMs in the follow-on evaluation. If they reviewed NOTAMs in the Cross-Sectional Study, then they reviewed NOTAMs in the follow-on evaluation. Participant explanations for why they did or did not review the NOTAMs remained the same as well. Those participants who did not review NOTAMs commented that they felt anything applicable to the flight would also be found in the ATIS, therefore they did not feel the need to review the NOTAMs.

Reviewing the release and aeronautical publications requires cognitive skills that may degrade from lack of use. Participants were measurably slower from the Cross-Sectional Study to the follow-on evaluation in reviewing the flight release and aeronautical publications. The A320 participants took on average 5.62 minutes longer to review the release and aeronautical publications. The B737 participants took on average

1.15 minutes longer to review the release and aeronautical publications. Three participants noted in the follow-on evaluation that they had challenges collecting the information they needed to review the release. These same participants had not expressed feeling any challenges collecting information in the Cross-Sectional Study, suggesting that skills like information collection in the context of the flight release may be susceptible to degradation.

Scenario 2: Pre-flight Preparations and Flight Deck Setup

Participants applied knowledge and cognitive skills to verify the loaded flight plan, prepare the flight deck, and brief the crew. The verbal protocol elicited participant knowledge and participant understanding and expectations of the flight that came from verifying the loaded plan, preparing the flight deck, and briefing the crew. Differences in participant actions (e.g., what systems they referenced, what they briefed, how they verified what was loaded) and differences in participants' understanding and expectations of the flight, and the knowledge they expressed through the verbal protocol are described below.

Scenario 2 Cross-Sectional Results

Participants approached this scenario in different ways. Those who had been away from flying for longer tended to spend several minutes re-familiarizing themselves with the flight deck, looking at and recalling where information was located, recalling different systems, and the layout of displays and systems. Several pilots (both recent and those who had been away from flying) reviewed and collected information from the standard instrument departure (SID) chart and flight release prior to reviewing the loaded flight plan and conducting the briefing. For example, they may collect and enter the local altimeter setting and top altitude of the procedure prior to conducting the briefing. Two participants entered the incorrect altimeter setting (one A320, one B737, both away from flying for 6-12 months). Three participants entered the incorrect top altitude (one A320, away for 6-12 months and two B737, one away for 6-12 months and one away for 12-24 months). The participants recognized their error and input the correct top altitude either during the briefing or during the next scenario.

All participants in the Cross-Sectional Study reviewed the loaded flight plan. However, those whose experience in the flight deck was more recent (current pilots and 6-12 month pilots) tended to perform their own review of the loaded flight plan and takeoff performance numbers shortly after entering the flight. These pilots scanned the loaded plan, consulting the release and EFB. Their review also typically included a more succinct and quicker review of other FMS pages (e.g., following a flow versus looking at the same pages multiple times in an attempt to find relevant information). Those who had been away from flying for 12 – 24 months (3 of 4 in the A320 and 3 of 4 in the B737) did not tend to review the loaded flight plan independently on their own. They only reviewed what was loaded in collaboration with the PM (e.g., the participant read the points while the PM checked against the chart or vice versa). These pilots tended to flip through pages in the FMS in search of information, making statement such as "let's see if I can remember," "I'm not sure I remember…," and "where is…". When discussing this during the verbal protocol, several pilots made statements such as they had "forgotten my flows" and "I don't remember everything that I'm supposed to." Knowledge that had degraded included declarative knowledge of where information could be found in the FMS and the flows to help guide information collection. Participants were able to recall what information they wanted to know, but they had challenges recalling where to find it (e.g., distance to KLAX, fuel prediction information, aircraft weight, flex or assumed temp). Some participants were ultimately able to recall some of this knowledge and their flows with time and cognitive effort. Three participants who had been away from flying for 12-24 months did not enable certain automated systems including the flight director (A320 and B737), autothrottle (B737), and LNAV and VNAV (B737).

Regardless of whether they reviewed the plan independently first, all pilots walked through the loaded flight plan in collaboration with their PM where one pilot read out the waypoints and constraints from the aeronautical publication while the other pilot checked this against the waypoints and constraints loaded in the FMS. Two pilots (one A320 and one B737), who chose to be the pilots who read the waypoints and constraints versus checking the FMS, did not use the EFB with the aeronautical charts but the flight release. Based on the verbal protocol, this could be evidence of degradation, but it is also complicated by managing procedures with a PM from a different Part 121 operator. Participants were unclear regarding why they chose to use the release versus the aeronautical publication.

To facilitate the review of the loaded flight plan, nine of the twelve A320 pilots leveraged the ND in PLAN mode to review the flight plan. One of the twelve B737 pilots leveraged the ND in PLN mode while the other eleven pilots used the CDU. From the verbal protocol, two of the A320 pilots who did not leverage the ND in PLAN mode (one 6-12 month pilot and one 12-24 month pilot) "forgot" that this was how they normally reviewed the plan, indicating that use of this system as a method for information collection and integration had degraded for these two pilots. For the B737 participants, none of the B737 pilots were used to using the PLN mode in their day-to-day operations. They tended to review what was loaded by looking at the CDU only, indicating that this is a difference in approach, not degradation.

Participants were provided with checklists, including a briefing guide, prior to Scenario 2, and they were given time to familiarize themselves with the checklists and briefing guide prior to entering the simulator for Scenario 2. Three participants (1 A320, 2 B737) who had been away from flying for 12-24 months took the time to walk through the checklists themselves while sitting in the simulator prior to starting the checklists with the PM. These participants did the briefing prior to conducting the checklists and were more efficient in completing the checklists. Two A320 and 1 B737 participant who had been away from flying did not conduct the briefing until doing the checklist and reaching that item (e.g., "Departure Briefing" or "Briefings"). Two of the 6-12 month A320 pilots forgot that the briefing guide was available to them, in-between reviewing the guide in the briefing room and then conducting the briefing on the flight deck of the simulator. In the verbal protocol, they mentioned "oh yeah, I forgot that was there." As a result, their briefings contained less planning. Despite briefing terrain, six of the A320 pilots and seven of the B737 pilots did not enable terrain (on the ND) when they briefed it. In the verbal protocol, these pilots stated that this was an oversight; they would normally have enabled terrain.

Reviewing the loaded flight plan, preparing the flight deck, and briefing the crew entails collecting information from the release and aeronautical publications, integrating that information to assess what is loaded and what is pertinent, performing estimations to assess if what is loaded is correct per the plan, making predictions to support developing a plan for the flight, developing a plan for the flight, particularly for the takeoff, and sharing and validating that plan with the other crew. The time it takes to complete actions like checklists, reviewing the loaded flight plan with the PM, and conducting the departure briefing can be indicative of challenges with collecting, integrating, estimating, predicting, planning and communicating; the cognitive skills and knowledge to support those skills may have degraded and therefore it takes longer to accomplish the associated tasks. The opposite could also be true; participants who take longer to brief, for instance, may be developing a more thorough plan. The average time in minutes that it took for pilots to conduct the briefing and to prepare the flight deck (e.g., review the loaded flight plan and complete the Preflight and Pushback checklists (A320) or the Before Start and Before Push (B737) checklists) is shown in Figure 12 and Figure 13.

Cross-Sectional Study findings based on 12 A320 participants preparing the flight deck for a flight from Phoenix (KPHX) to Los Angeles (KLAX)

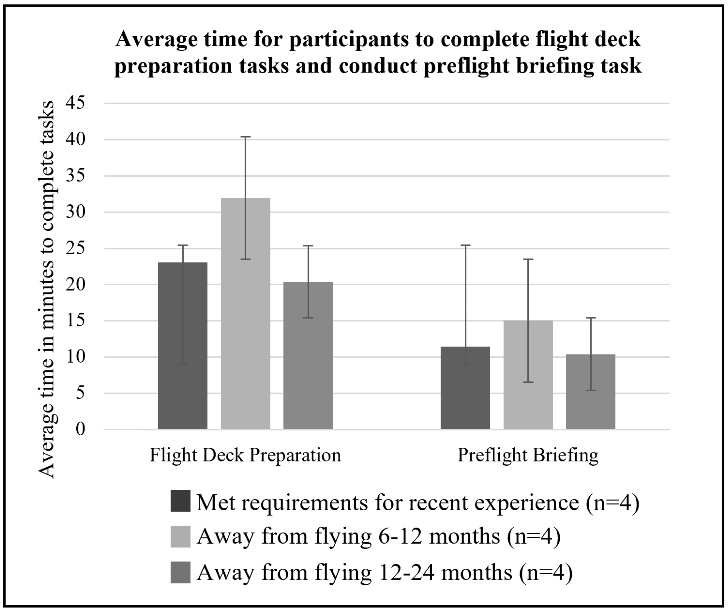


Figure 12. Average time in minutes for A320 participants to complete flight deck preparations and conduct preflight briefing during Cross-Sectional Study.

Cross-Sectional Study findings based on 12 B737 participants preparing the flight deck for a flight from Phoenix (KPHX) to Los Angeles (KLAX)

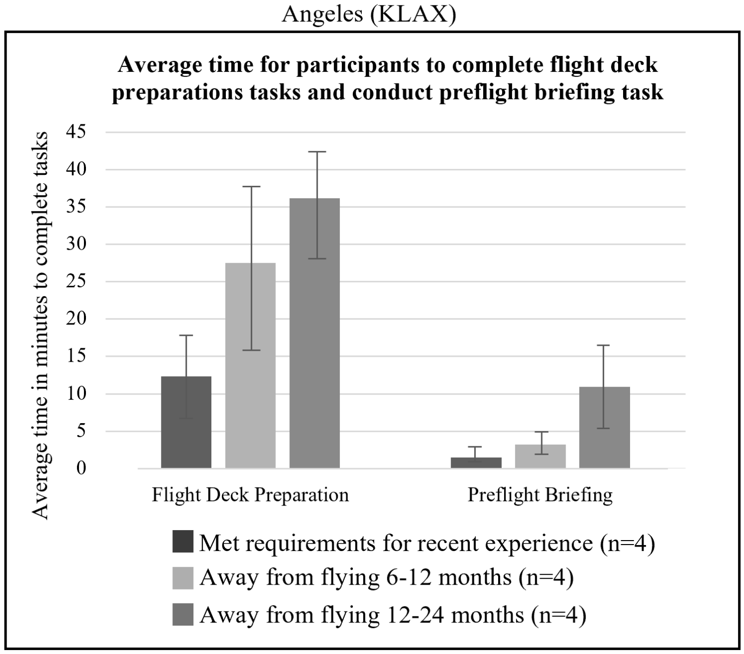


Figure 13. Average time in minutes for B737 participants to complete flight deck preparations and conduct preflight briefing during Cross-Sectional Study.

For the A320 pilots, there were no statistically significant differences in how long it took for the different participants to conduct the preflight briefing, $F(2, 9) = 1.61$, $p = .25$, $\eta_p^2 = 0.26$, or prepare the flight deck, $F(2, 9) = 1.41$, $p = .24$. For the B737, the ANOVA analysis indicated statistically significant differences in how long it took for the different participants to prepare the flight deck, $F(2, 9) = 17.23$, $p < .001$, $\eta_p^2 = 0.79$. Pairwise comparisons indicate that pilots who had not been flying for 12 to 24 months were significantly slower than pilots who were current ($p = .01$). The ANOVA analysis also revealed statistically significant differences in how long it took for the different participants to conduct the preflight briefing, $F(2, 9) = 24.62$, $p < .001$, $\eta_p^2 = 0.84$. Pairwise comparisons indicate that pilots who had not been flying for 12 to 24 months were significantly slower than pilots who were current ($p = .005$).

The B737 results indicate that for this aircraft, participants who had been away from flying took on average 9 minutes longer to complete the preflight briefing and the flight deck setup. Researcher observations of participant actions and verbalizations suggests that the B737 pilots who had been away from flying had more challenges collecting information such as finding the right pages in the FMS, locating systems and information required by checklists, and recalling what they needed to check to verify all aircraft systems. B737 pilots who took longer to conduct the briefing exhibited challenges collecting all the information that they needed to brief and recalling everything that they needed to brief. Researcher observations of participant actions and verbalizations suggests the A320 pilots who had been away from flying for 12-24 months did not cover all topics in their briefings; topics not covered in the briefings included terrain, weather, and rejected takeoff considerations. One 6-12 month pilot did not brief constraints on the departure.

Scenario 2 Longitudinal Results

Comparing the Cross-Sectional Study to the Longitudinal Study, there were four A320 participants and four B737 participants who were in the 6-12 month group in the Cross-Sectional Study and in the follow-on evaluation, had then been away from flying for 12-24 months. The participants who returned for the follow-on evaluation and who had then been away for 12-24 months exhibited some of the same loss of knowledge as those in the 12-24 month group in the Cross-Sectional Study. For the A320 pilots, this meant that pilots who had enabled terrain in the Cross-Sectional Study did not enable terrain in the follow-on evaluation. Similarly, some of the pilots who returned had enabled constraints in the Cross-Sectional Study but when they returned, did not enable constraints and forgot that they could use the ND in PLAN mode. Two of the pilots who returned set the wrong altimeter, and three had the wrong flaps setting. In the B737, two of the pilots forgot to enable terrain who had enabled it in the Cross-Sectional Study and one pilot forgot to enable LNAV and VNAV who had remembered in the Cross-Sectional Study. In the verbal protocol, most of those pilots who returned mentioned that they had forgotten their flows and had challenges remembering where to collect information they know they needed. This supports that declarative and procedural knowledge of where information could be found in the FMS and the flows to help guide information collection degrade. The degradation of this knowledge impacts cognitive skills such as information collection, integration, estimation, and planning.

Scenario 3: Area Navigation (RNAV) Departure from Phoenix (KPHX)

Participants executed a takeoff from Phoenix in this scenario, using cognitive skills and knowledge to plan and control airspeed, altitude, thrust, and trajectory during the takeoff and initial climb, leveraging the FMS computed profile and aeronautical publications. Differences observed in participant actions, such as which systems they enabled and whether they proactively managed their flightpath, differences in their responses to the verbal protocol, and how these differences are reflected in visualizations of their flightpath are described below.

Scenario 3 Cross-Sectional Results

All participants, regardless of their group, collected airspeed, altitude, climb rate, flight modes, and constraints from the PFD, ND, and FMS. However, the extent to which they collected this information varied, and there was potential evidence of knowledge degradation related to automated systems and skill degradation in terms of being able to quickly collect and integrate information. Two of the 12-24 month A320 pilots and one of the 12-24 month B737 pilots forgot to enable their flight directors; this indicates potential knowledge degradation related to recall of flows, knowledge of interactions between FMS and modes, and potential degradation of collection and integration, as the mode indicators on the PFD reflect whether the flight director is enabled. All three pilots realized after taking off that there was an issue. One of the A320 pilots noticed immediately (within seconds of lifting off the ground), recognized they had forgot the flight director, and enabled the flight director. The other A320 pilot and the B737 pilot took longer to realize what was wrong (10-15 seconds after lifting off the ground), recognized they had not enabled the flight director, but then could not recall where the button/switch to enable the flight director was located, making statements indicating they could not find the button or switch on the panel and asking the PM for assistance. Another B737 in the 12-24 month group had a momentary issue recalling where the button to fully engage the autopilot was located. They hit the approach button first (APPR). The PM corrected the participant, the participant made a statement, "Where is that button?" They hit the control wheel steering (CWS), realized that was not right, and then located the command mode (CMD) button. One 6-12 month B737 pilot had a moment where they wondered why the aircraft was not accelerating past 220 knots. This indicated that they were collecting and integrating information from the PFD and ND. They collected additional information from the EFB, noticed the speed constraint, and then realized they had not turned on constraints and they had not briefed that constraint, which was a gap in Scenario 2 with implications for Scenario 3.

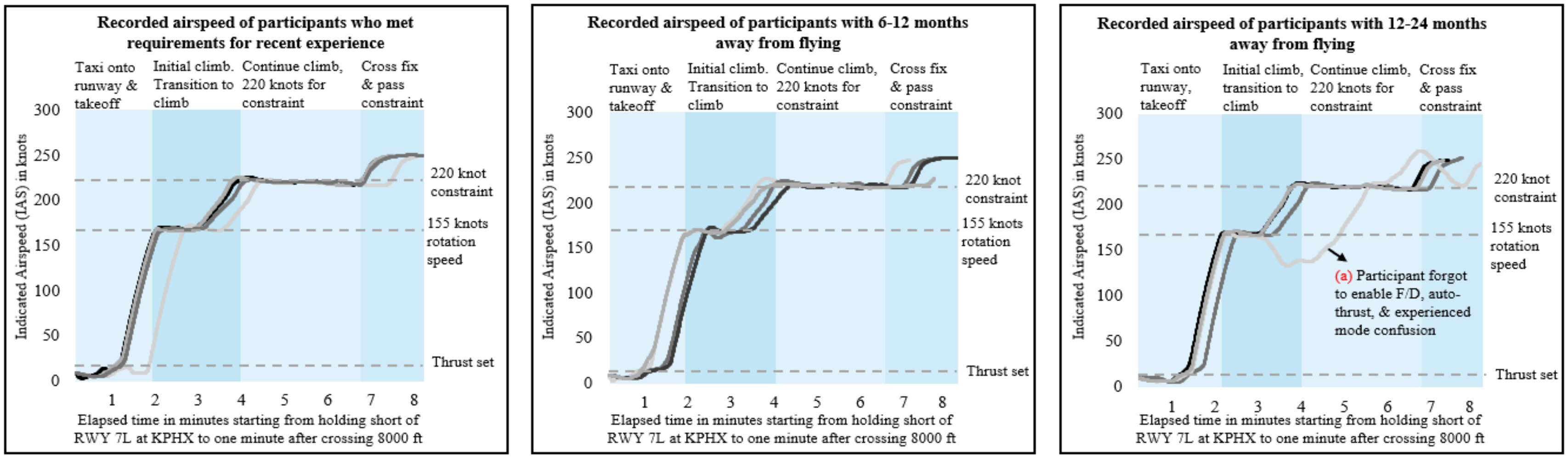
None of the A320 or B737 pilots considered Phoenix temperature, airport altitude, or Phoenix terrain to be concerning factors in this scenario. When asked why, pilots leveraged local knowledge and knowledge of the aircraft performance. Of the twelve A320 pilots and twelve B737 pilots, only two A320 pilots and three B737 pilots expressed explicit expectations they had formed based on these factors and the effects of these factors on their takeoff and initial climb. For example, these pilots had formed expectations of where they might rotate based on the length of the runway given the expected performance of the aircraft with the temperature and reduced thrust takeoff. These pilots also spoke more in-depth about terrain considerations and articulated thoughts about the relationship between temperature and airport altitude. There were no obvious group difference in terms of pilots who formed more expectations from temperature, airport altitude, and terrain factors versus those who did not.

Of the twelve A320 pilots and twelve B737 pilots, four A320 pilots (two current, one 6-12 months, and one 12-24 months) and two B737 pilots (one current, one 6-12 months) requested higher from ATC. All six requested higher after reaching 8000 ft, the top altitude they were cleared to. Most of the pilots, regardless of whether they requested higher or not, leveraged local knowledge and said they felt it was unusual for the Phoenix TRACON not to clear them to a higher altitude. For those who requested higher, this was a reason to reach out. For those who did not request higher, 16 stated that if ATC had not provided higher, there was probably a good reason, which was their logic for not reaching out. These pilots stated they would request higher given more time. Some pilots said they would have asked for higher around the time the scenario ended (the scenario ended 1 minute after 8000). Others commented that they would wait a minute or two longer. Of those who did not request a higher altitude from ATC, two pilots who had been away from flying acknowledged that they simply did not think about asking and that this was partially due to workload in managing the takeoff and climb.

Figure 14 and Figure 15 on the following pages depict the airspeed for the A320 and B737 pilots, separated out by participant group and aircraft type. Individual images of these graphs can be found in Appendix O – Individual Graphs. Note that the B737 pilots did not taxi from the holding short position so the B737 graphs begin on the runway. In addition, the B737 participants reached 8000 ft more quickly than the A320 pilots; the B737 scenarios ended just prior to or as they were crossing the MASVE constraint while the A320 participants' scenario ended shortly after crossing MASVE. Changes in airspeed during takeoff, initial climb, and adherence to the 220 knot constraint at MASVE can be seen in the graphs in these figures. The differences in pilot knowledge and cognitive skill did not appear to have a large effect on airspeed, with two exceptions. Those two exceptions were the two pilots who forgot to enable their flight directors in the A320 and B737, respectively. The varying airspeed for these two pilots can be seen in the 12-24 month graphs in these two figures. The A320 pilot in particular had additional knowledge and skill degradation beyond omission of their flight director; this is detailed in Figure 16 on page 57. This participant struggled to collect and recall correct autoflight modes and FMS interactions with autoflight modes. Collecting airspeed, altitude, and pitch information, the participant did recognize the aircraft was slowing when it should not have been. The participant did prioritize managing the flightpath at this point; when they were uncertain of the issue and how to resolve it, they disengaged the automation and flew manually.

A320 speed management during takeoff and climb

Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

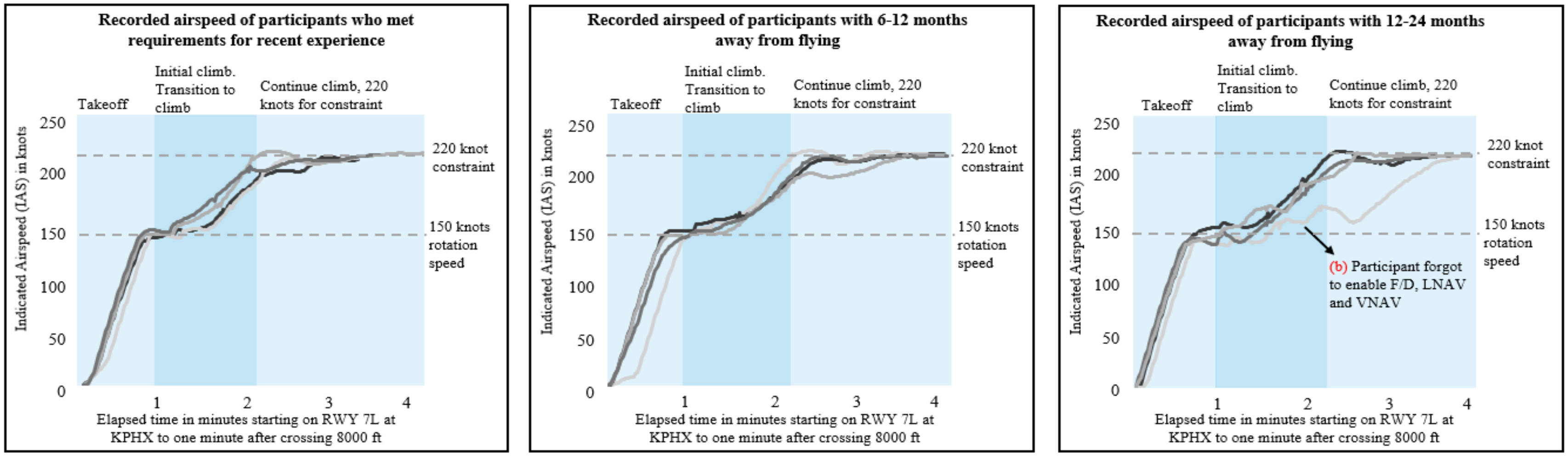
25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

Figure 14. A320 participant's airspeed during Scenario 3, Area Navigation (RNAV) departure from Phoenix (KPHX)

Differences in pilot knowledge and cognitive skill did not appear to have a large effect on airspeed with one exception. One participant who had been away from flying for 12-24 months forgot to enable their flight director (labeled "**a**").

B737 speed management during takeoff and climb

Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of B737 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

25% (n = 4) of B737 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

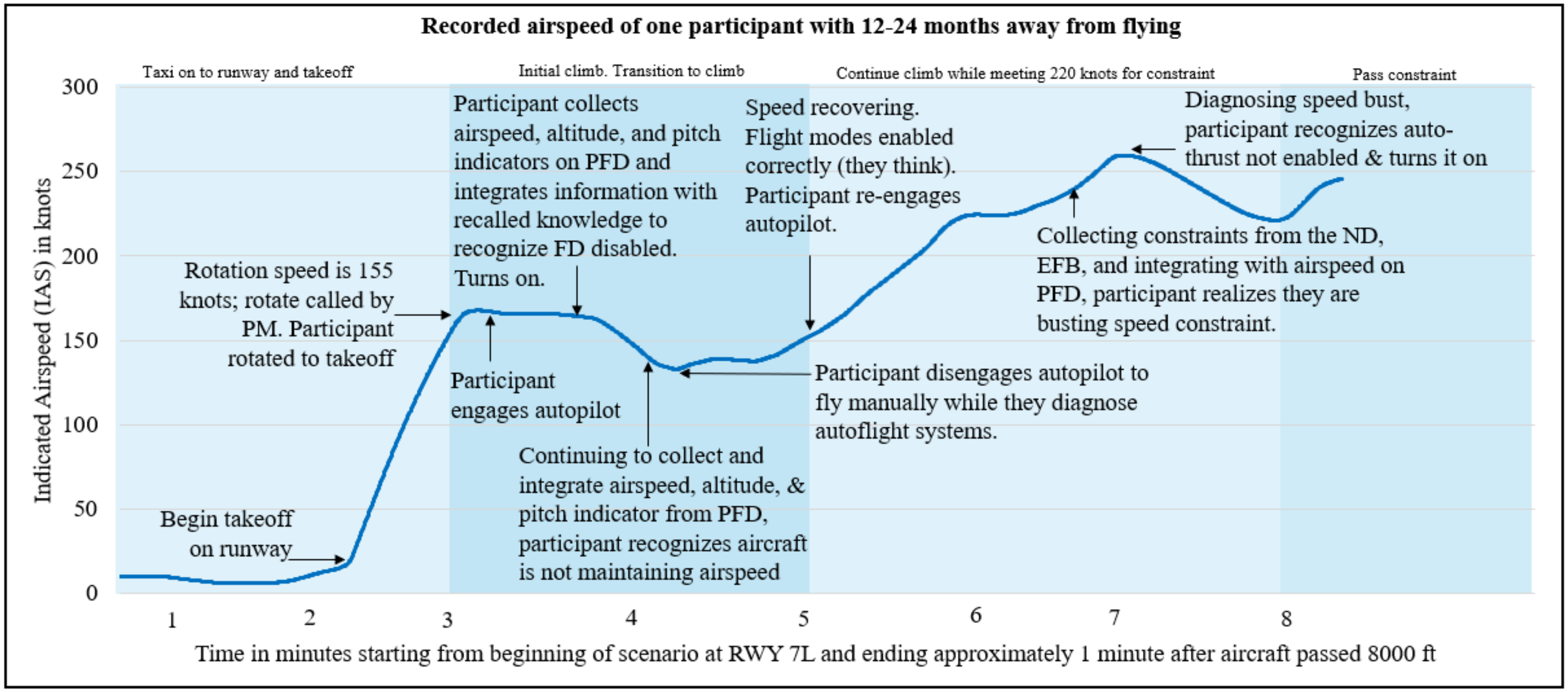
25% (n = 4) of B737 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

Figure 15. B737 participant's airspeed during Scenario 3, Area Navigation (RNAV) departure from Phoenix (KPHX)

Differences in pilot knowledge and cognitive skill did not appear to have a large effect on airspeed with one exception. One participant who had been away from flying for 12-24 months forgot to enable their flight director (labeled **"b"**).

A320 speed management during take-off and climb

Cross-Sectional Study findings from one participant flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One of four (25%) A320 participants with 12-24 months away from flying on the day of the Cross-Sectional Study data collection.
Percentage is based on four participants with 12-24 months away from flying.

Figure 16. Example of effects of procedural and flight systems knowledge degradation and degradation of cognitive skills information collection and integration on airspeed for A320 pilot who had been away from flying for 12-24 months.

Another potentially noticeable difference between participant groups was when participants chose to engage autopilot, shown in Table 14 and Table 15. This is relevant because knowledge and cognitive skill degradation may be one of the reasons behind why participants chose to engage autoflight systems. For both aircraft types, the 6-12 month pilots were more likely to hand-fly the aircraft for longer than the current participants and for longer than the pilots who had been away for 12-24 months. The standard deviations suggest this is just a trend and may warrant further evidence. However, in the verbal protocol, the 6-12 month participants mentioned that because they had been away from flying, they wanted to fly manually and felt confident in their cognitive abilities related to information collection, integration, prediction and estimation to fly manually. In contrast, the 12-24 month participants for both aircraft types tended to engage autopilot earlier than both the current participants and the 6-12 month participants. In the verbal protocol, these participants stated that they were less confident and wanted to engage autoflight systems earlier to ensure a stable aircraft. In general, the B737 pilots tended to fly the aircraft manually for longer than the A320 pilots. This difference may be related to habit and/or operational procedures.

Table 14. Average altitude (mean and standard deviation for altitude) that A320 participants engaged autopilot during takeoff.

Average altitude A320 participants engaged autopilot during takeoff when flying KEENS RNAV Departure from Phoenix		
	M	*SD*
Current	2475	1282.8
Away from flying 6-12 months	3135	3248.3
Away from flying 12-24 months	1675	805.0

Table 15. Average altitude (mean and standard deviation for altitude) that B737 participants engaged autopilot during takeoff.

Average altitude B737 participants engaged autopilot during takeoff when flying KEENS RNAV Departure from Phoenix		
	M	*SD*
Current	3825	1090.5
Away from flying 6-12 months	5875	232.9
Away from flying 12-24 months	3725	2549.9

Scenario 3 Longitudinal Results

For Scenario 3, the pilots who returned were able to recall and respond adequately to manage their takeoff and initial climb with minimal consequences to the flightpath. Consequences to the flightpath as a result of incorrect automation settings were avoided when the three participants who had set the wrong flaps settings in Scenario 2 caught their mistakes prior to taking off. The one pilot who forgot to enable LNAV and VNAV in the B737 during Scenario 2 enabled these modes shortly after taking off, when putting the aircraft in autopilot did not respond as they expected it to, and they were able to diagnose why. Across all eleven participants who returned, takeoffs from the Cross-Sectional Study in comparison to the Longitudinal Study were executed similarly. For example, Figure 17 depicts the airspeed of each of the A320 participants who participated in both the cross-sectional and Longitudinal Study and it can be seen by looking each graph that no participant deviated substantially in airspeed from the Cross-Sectional Study to the Longitudinal Study.

There was one participant who did struggle slightly to execute a smooth transition from takeoff thrust to climb thrust. They commented that they had a hard time seeing the setting. This resulted in a slight deviation in their airspeed, which is indicated in Figure 17. Altitude was similarly consistent from the Cross-Sectional Study to the Longitudinal Study for all eleven A320 and B737 participants who returned. Pilots who requested higher from ATC in the Cross-Sectional Study requested higher in the Longitudinal Study. One participant who had not requested higher in the Cross-Sectional Study requested higher in the Longitudinal Study, and when queried in the verbal protocol, acknowledged they had remembered this from the Cross-Sectional Study. This participant indicated that they felt operationally, they would have asked versus waiting as they did in the Cross-Sectional Study.

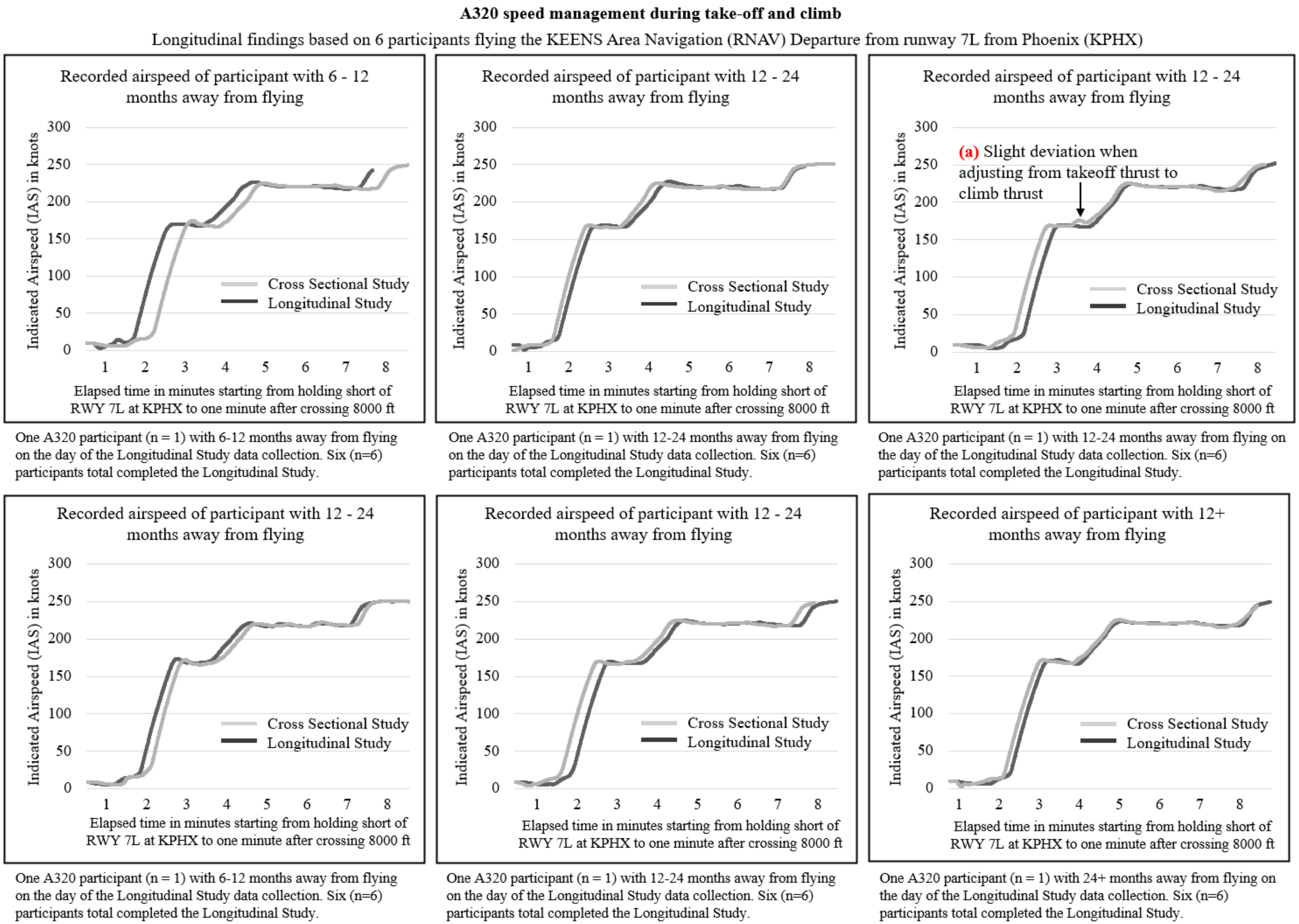


Figure 17. Six A320 participants airspeed management in the Cross-Sectional Study and Longitudinal Study.
One participant struggled with a smooth transition from takeoff thrust to climb thrust (labeled "a"), saying they had a hard time seeing the setting.

Scenario 4: Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude

In this scenario, participants managed the aircraft through latter climb, and at FL280, ATC requested participants to climb to FL320 in two minutes or less. Participants used knowledge and cognitive skills to decide how to respond to ATC's request and to execute a response. The verbal protocol elicited participant knowledge and underlying decision-making behind their actions in response to ATC. Differences in participant actions and knowledge, as elicited by the verbal protocol, are described below.

Scenario 4 Cross-Sectional Results

Upon receiving the call from ATC, which included both a clearance to FL340 and the request from ATC to climb from FL280 to FL320 in two minutes or less, all of the participants went to the mode control panel to enter FL340. All participants entered the altitude; however, 9 of 12 A320 participants (consisting of current, away for 6-12 months, and away for 12-24 months) and 8 of 12 B737 participants (consisting of current, away for 6-12 months, and away for 12-24 months) did not confirm with their PM the altitude clearance but transitioned to the next task of climbing to FL320 in two minutes or less. Participants took one of three approaches: (1) they reduced airspeed which has a corresponding effect of increasing the climb rate, (2) they used vertical speed, or (3) they said unable. Table 16 and Table 17 contain the totals for each aircraft type for the different possible participant responses and approaches.

Table 16. Proportion of A320 participant 'yes' and 'no' responses to ATC's request in Scenario 4. If participants said 'yes,' the proportion that reduced airspeed or used vertical speed is also provided.

	A320	
Response to ATC's Request	**Yes**	**No**
Reduce airspeed	9	--
Use vertical speed	2	--
Said unable	--	1
Total	11	1

Table 17. Proportion of B737 participant 'yes' and 'no' responses to ATC's request in Scenario 4. If participants said 'yes,' the proportion that reduced airspeed or used vertical speed is also provided.

	B737	
Response to ATC's Request	**Yes**	**No**
Reduce airspeed	2	--
Use vertical speed	4	--
Said unable	--	6
Total	6	6

Nine of the A320 participants and two of the B737 participants chose to reduce airspeed to meet the request. Two of the A320 participants and four of the B737 participants used vertical speed to meet the request. There did not appear to be a relationship between time away from flying and how the participants chose to meet the request. However, there did appear to be a relationship between collecting information and executing cognitive skills in relation to collected information in order to meet the ATC's request. This is a recurring process in which the participants needed to re-assess their ability to meet ATC's request on a recurring basis. Based on the frequency with which pilot participants talked about this process in the verbal protocol and their behaviors during the scenario (e.g., making adjustments to the flight controls to expedite the climb), there appeared to be a difference in the frequency with which participants completed the cognitive process of assessing the current state of the flightpath and making adjustments.

Figure 18 shows changes in indicated airspeed and climb rate as A320 participants adjusted flight controls to meet the constraint. The figure shows differences in how A320 pilots responded to ATC's request by manipulating airspeed (n = 9), by using vertical speed (n = 2,), or by saying unable (n = 1). Current pilots who manipulated airspeed (labeled **"a"** in graphs), adjusted the airspeed more frequently than pilots who had been away from flying 12-24 months (labeled **"b"** in graphs). Manipulations of airspeed or vertical speed had corresponding effects on the climb rate (**"c"** and **"d"**). While not a large difference, this suggests pilots who had been away for longer may have been executing cognitive skills of information collection, integration, and estimation at a slightly slower frequency. Participants who had been away from flying 12-24 months were also slightly slower (5-8 seconds) to take action after receiving the request from ATC (**"e"**).

Of the twelve A320 participants, only one participant, who had been away from flying for 12-24 months, said unable. In comparison, six of the twelve B737 participants said unable. Of the six B737 participants who said unable, two were current, one had been away from flying for 6-12 months, and three had been away from flying for 12-24 months. In understanding their reasoning, participants were not comfortable with changing the current performance of the aircraft when they have the option of saying unable. Participants who had been away from flying were less comfortable with changing the performance of the aircraft for a variety of reasons which included degraded knowledge. Upon receiving ATC's request, these participants who said unable assessed that the aircraft's climb rate of 1500 ft/min was not enough to make the constraint (e.g., they performed the estimations correctly). However, to change the climb rate to make the constraint, some participants had challenges recalling the lowest "safest" airspeed the aircraft could slow down to (e.g., green dot indicator in the A320), recalling implications of slowing to that speed, and/or recalling enough information to make a judgement regarding the lowest 'safest' airspeed.

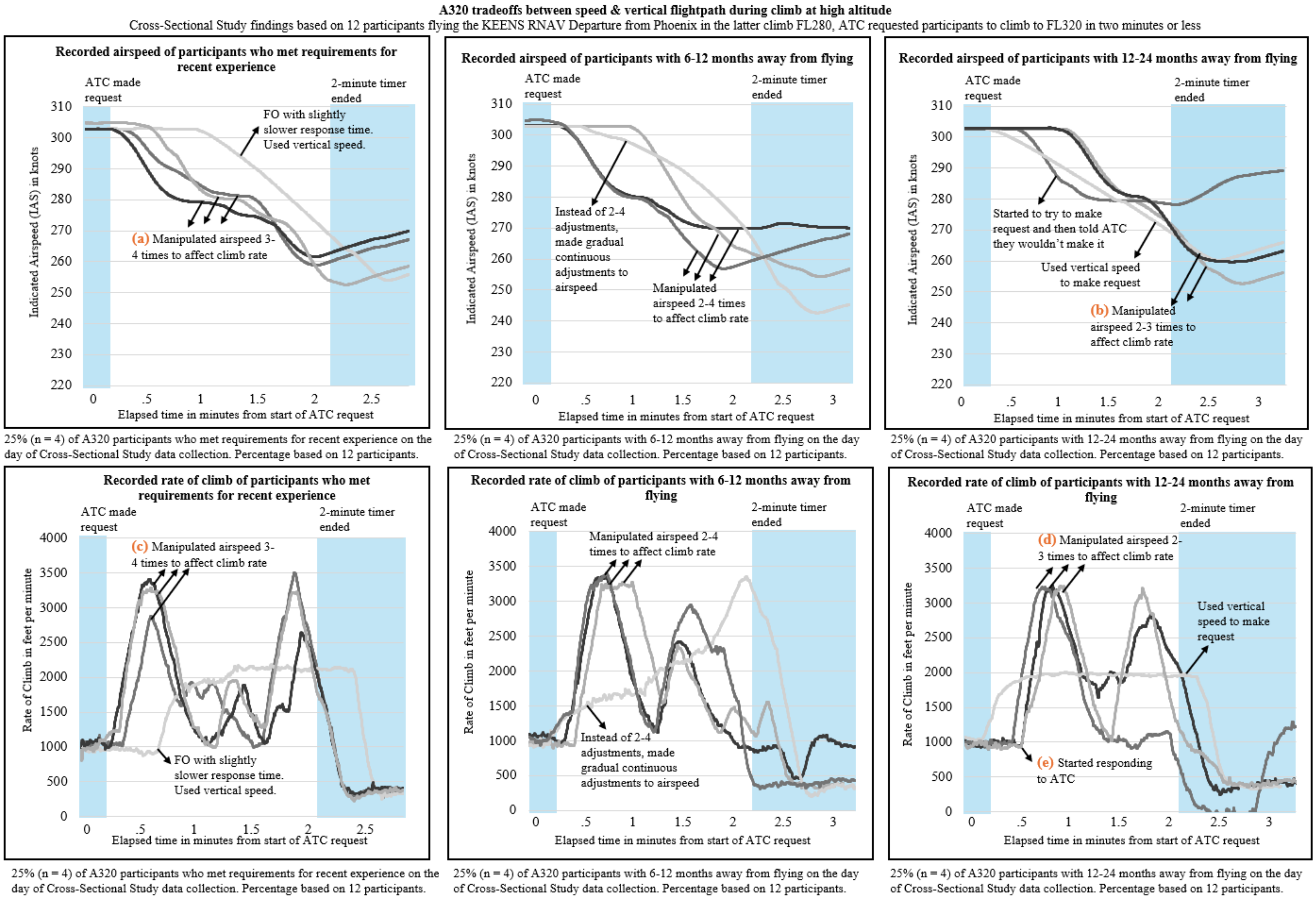


Figure 18. A320 pilots climb rate and airspeed during Scenario 4 (See paragraph in previous text for references to “a”, “b”, “c”, and “d”)

Of those who did respond to ATC's request, there were a few participants who appeared less knowledgeable of the potential impact of climbing at high altitude. A follow-up question in the verbal protocol posed a similar hypothetical situation for the participants. Participants were asked how they would assess if they could make a request from ATC to climb to FL360 from FL280 in five minutes or less. Given the higher altitude, this would be a much harder request accounting for the performance of either aircraft. Three participants (two A320, one B737) articulated the calculation for the required rate of climb and said they would accept the request. The other 21 participants said they would respond unable due to the reduced performance of the aircraft at the higher altitudes.

Scenario 4 Longitudinal Results

In comparison from the Cross-Sectional Study to the Longitudinal Study, not all participants responded to ATC in the Longitudinal Study in the same way they had in the Cross-Sectional Study. Table 18 provides the cross-tabulation of the relationship between participant yes/no responses to ATC. Six participants flipped their responses to ATC (4 A320 participants and 2 B737 participants), meaning four participants who said yes to ATC in the cross-sectional evaluation said no in the Longitudinal Study and two participants who said no in the Cross-Sectional Study said yes in the longitudinal evaluation. When those who had said yes in the Cross-Sectional Study but said no in the Longitudinal Study were asked about their reasoning, they stated that they did not want to do the math, suggesting that their skills had possibly degraded. The five participants who said yes took the same approach to meet the request, whether that was manipulating vertical speed or airspeed. Of these five, however, three of those participants (2 A320, 1 B737) did the math incorrectly for the needed rate of climb. The calculation presented by ATC's request was slightly more challenging than in the Cross-Sectional Study. The division was not exact, so it is possible this is why several of the participants declined to attempt the request and several miscalculated. However, this could also be evidence of skill degradation, in line with findings from the Cross-Sectional Study that participants who had been away from flying were less comfortable with changing the performance of the aircraft.

Table 18. Cross-tabulation of the relationship between participant 'yes' and 'no' responses to ATC for the cross-sectional and Longitudinal Study. Yes/yes refers to participants who said yes in both studies; no/no refers to participants who said no in both studies.

A320 Participants		**Longitudinal Study**	
	Response to ATC	**Yes**	**No**
Cross-Sectional Study Response:	**Yes**	2	3
	No	1	0
	Total	3	3

B737 Participants		**Longitudinal Study**	
	Response to ATC	**Yes**	**No**
Cross-Sectional Study Response:	**Yes**	1	1
	No	1	2
	Total	2	3

Scenario 5: Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise

For Scenario 5, participants used cognitive skills and knowledge to enter a hold in the FMS, manage fuel, estimate the effects of fuel burn on the flightpath, and make decisions and a plan for holding or going to an alternate. The verbal protocol elicited the knowledge and reasoning behind the actions and decisions participants made. Differences in responses to the verbal protocol and differences in participant actions, including collecting and entering the hold information, communications with their PM and dispatch, and interactions with systems, are described below.

Scenario 5 Cross-Sectional Results

Upon receiving the request to hold, participants first collected and entered the hold information in the FMS. They collected the information they needed to enter the hold from the EFB and then found the correct page in the FMS to enter the hold information. The hold populated in the FMS with the inbound course, which was not the published hold, so participants needed to update the inbound course, ensure the leg distance, and direction of turn was correct. All participants appeared to verify that the hold looked correct by looking at the depiction of the hold on the ND. For example, participants made statements to the PM such as, "That looks right to me. That look right to you?" However, not all participants entered the hold information correctly. This implies that they did not collect and integrate information from the EFB to verify the hold was entered correctly, as shown in Table 19. There did not appear to be a clear relationship between entering the hold incorrectly and time away from flying. During the verbal protocol, three pilots realized they had entered the hold incorrectly when answering questions regarding how they programmed the hold. The realization came when asked where they had collected information from in order to enter the hold and/or how they had verified the hold was correct. As they answered the question, they realized they had not actually collected the correct information and/or they had not actually verified the hold correctly. These pilots all mentioned that in actual operations, they would hope and expect the PM to catch their error.

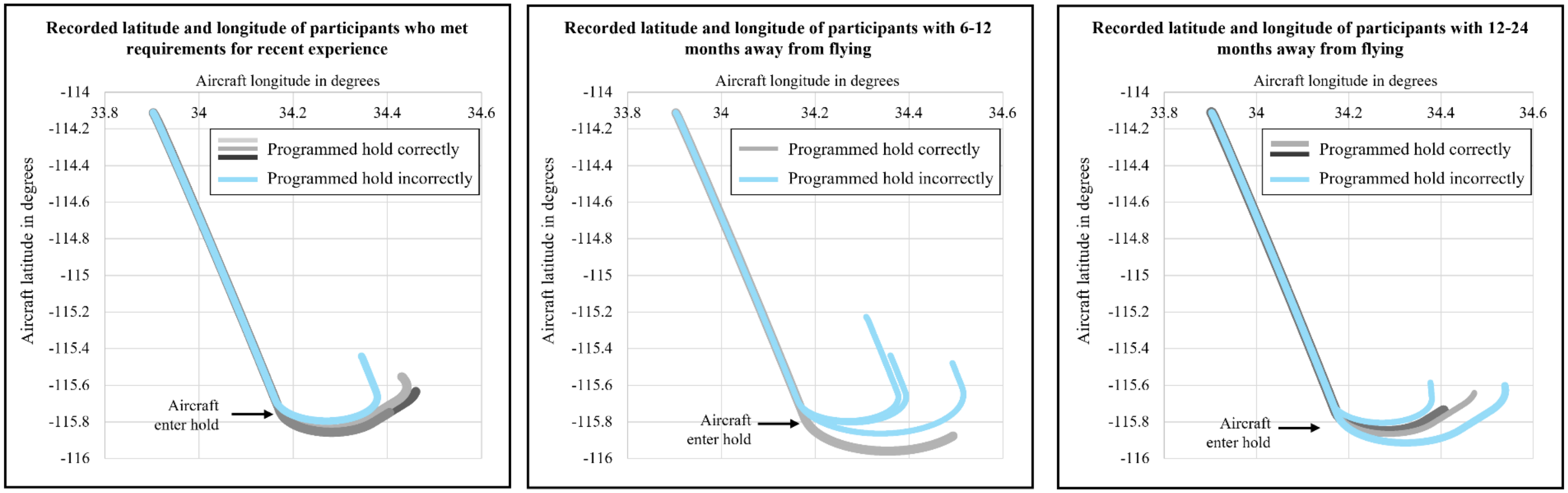
Table 19. Number of A320 and B737 participants who entered the hold information correctly.

	A320		**B737**		**Total**	**Total**
Entered hold correctly:	No	Yes	No	Yes	**Incorrect**	**Correct**
Current	1	3	2	2	3 (12.5%)	5 (21.0%)
Away 6-12 months	3	1	3	1	6 (25.0%)	2 (8.0%)
Away 12-24 months	2	2	1	3	3 (12.5%)	5 (21.0%)
Total	6 (50%)	6 (50%)	6 (50%)	6 (50%)	12 (50%)	12 (50%)

Incorrect holds can be partially visualized by plotting the latitude and longitude as shown in Figure 19 and Figure 20. The differences in latitude and longitude reflect (1) the different speeds and (2) the different holding criteria that participants entered when programming the hold. Six of twelve A320 participants and six of twelve B737 participants programmed the hold incorrectly. Incorrectly programmed holds are highlighted in blue in the graphs in Figure 19 and Figure 20. For the A320 participants, these holds differed primarily in that participants entered the wrong course information. The individuals who entered the wrong hold information were not all pilots who had been away from flying. It was fairly evenly distributed across participant groups. In four cases across both groups, pilots entered an incorrect leg distance. In the B737, one current pilot entered the hold as left-hand turns instead of right-hand turns. One of the B737 pilots who had been away from flying for 12-24 months changed the flight route in the process of entering the hold. Two pilots in the 6-12 month group held at close to their cruise speed of 270 knots.

A320 aircraft latitude and longitude when executing a hold in cruise.

Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

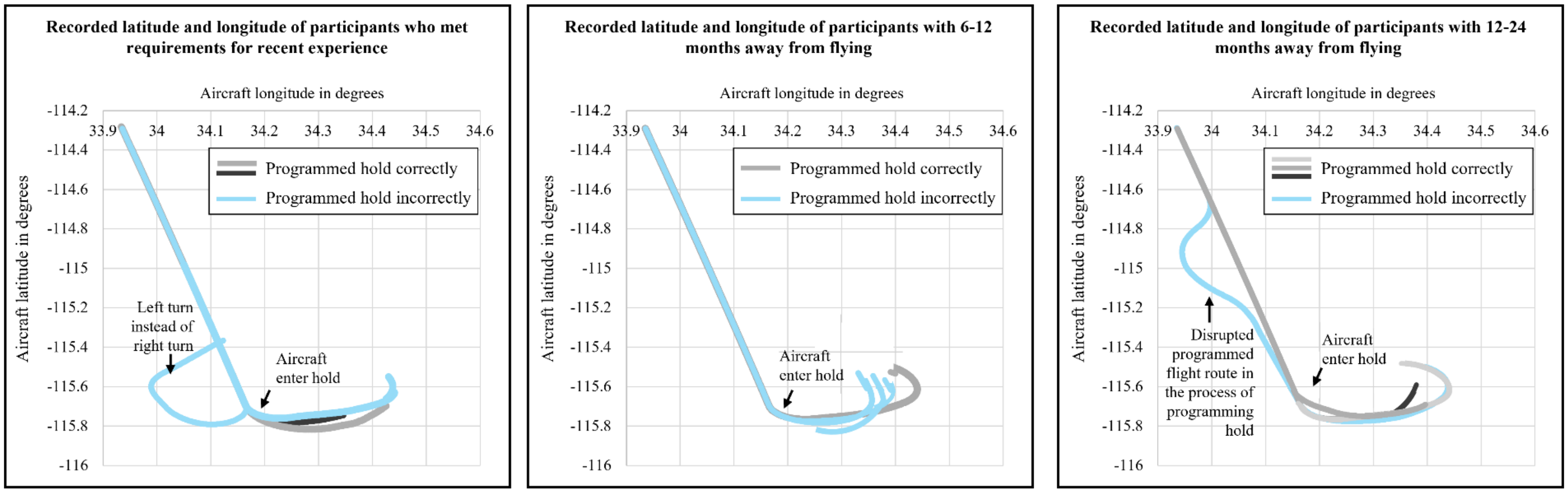
25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

Figure 19. Visualizations of A320 participants' latitude and longitude in degrees during Scenario 5, Managing ATC Interventions that Impact FPM during En Route Cruise.

B737 aircraft latitude and longitude when executing a hold in cruise.

Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of B737 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

25% (n = 4) of B737 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

25% (n = 4) of B737 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

Figure 20. Visualizations of B737 participants' latitude and longitude in degrees during Scenario 5, Managing ATC Interventions that Impact FPM during En Route Cruise.

After entering the hold information, participants needed to assess whether they had enough fuel to hold as long as the “expect further clearance” or EFC time implied they may need to hold for. Differences emerged around the degree to which participants evaluated different alternate options and what they considered when evaluating options other than the provided alternate. Another difference was in how participants considered how much fuel was available to them for holding. For example, in the A320, there is a Fuel Prediction page that provides automated information regarding fuel burn, planned fuel, and fuel availability. In the B737, if the pilot enters the ETC, they are provided with information regarding how long they can hold for. For some pilots, there were knowledge gaps regarding where and how they might use information automation (IA) systems to help formulate a plan. Three of the 12-24 month pilots across both groups initially struggled with identifying how much fuel they felt they needed to reach their alternate with issues recalling how to use systems to help make a plan playing a role. Another difference emerged in how pilots responded to receiving the hold. Some pilots slowed down upon receiving the request to hold; these pilots said that they did this to conserve fuel and to make time for themselves. Pilots who requested to slow belonged to all three groups, so this was not linked to time away from flying.

As with Scenario 4, there was a cyclical component to Scenario 5. The participants needed to update their plan for how long they could and would hold. The EFC given by ATC was 55 minutes and was intended to put the pilots in a position where if they held the entire time, they would risk being unable to make it to their alternate. All pilots had some plan for how long they would hold for, and none of the pilots intended to hold for the whole 55 minutes. What differed between pilots was the thoroughness of their plan. Thoroughness depended on the additional information they collected. The frequency and intended approach for updating this plan also differed between pilots. Some of the participants made a plan that consisted of a “bogey” fuel as they called it or a target fuel level where they felt they would then need to leave the hold and proceed to their alternate. These pilots then relaxed, talked socially with the pilot monitoring, or finished other flight deck tasks. They monitored entering the hold, but they did not revisit or change their plan, nor did they consider other alternates. In the verbal protocol, their reasoning was because they were comfortable with what they had determined and did not feel they needed to re-evaluate until they got close to the “bogey” fuel. Other participants spent their time iterating through possible alternates, considering and discarding possible options that would allow them to hold longer and/or had less uncertainty (e.g., returning to Phoenix, where the weather was a known quantity because they had just left). These participants tended to have more thorough plans regarding how they would proceed in the hold. These actions indicate distinct differences in participant skills of planning and prediction. Differences in participant skills of planning and prediction did not differ by group and were not a result of being away from flying.

Scenario 5 Longitudinal Results

Of those who returned, five participants had programmed the hold correctly and six participants (3 in the A320 and 3 in the B737) had programmed the hold incorrectly in the Cross-Sectional Study. Two participants in the Longitudinal Study once again entered the wrong hold information; the other four participants corrected their mistakes from the Cross-Sectional Study and entered the hold information correctly. This result does not support the potential for this knowledge to degrade; however, it also does not prove this knowledge does not degrade. For this particular scenario, this result highlights the impact of recall, where five months later, these four participants recalled entering the hold and recalled enough of that circumstance to adjust accordingly.

In terms of planning, all eleven participants executed similar plans as they had in the Cross-Sectional Study. One difference from the Cross-Sectional Study was the time it took for participants to find and assess how much fuel they had and how much fuel they needed. Some participants took longer in the follow-on evaluation to find the information they needed to make estimations and inform their decision making and planning. This included participants who were able to program the hold correctly, suggesting there is not necessarily a relationship between collecting and integrating the information to program the hold and collecting and integrating the information to develop a plan for holding. Where there was not a knowledge gap in the Cross-Sectional Study, there was some evidence of degradation in the follow-on evaluation. Participants were still able to develop a plan, and the plan was similar to what they developed in the Cross-Sectional Study; it simply took longer or involved more trial and error to find the information they wanted (e.g., current fuel burn, fuel to hold for the entire EFC, etc.) and/or make estimations based on that information.

Scenario 6: Energy Management during RNAV Arrival Descent to Los Angeles (KLAX)

In this scenario, participants managed the aircraft through arrival descent, which included ATC issuing a speed constraint at the beginning of the arrival. Participants used knowledge and cognitive skills to ensure conformance to published altitude restrictions while adhering to the issued speed constraint. The verbal protocol elicited participant knowledge and cognitive skills used to manage their flightpath during the arrival. Differences in responses to the verbal protocol and differences in participant actions to adjust their energy management strategy and compensatory adjustments to aircraft pitch and rate of descent are described below.

Cross-Sectional Results

All participants leveraged speed brakes to manage descending while slowing down and meeting the altitude constraints at every waypoint on the arrival. Participants differed in terms of where they collected information regarding their vertical flightpath and potential deviation, and the degree to which they estimated and then predicted the need for speed brakes to stay on the path. Nine of twelve A320 pilots applied speed brakes immediately to slow down when initially receiving the request from ATC to slow. These pilots all had an intuitive expectation based on knowledge of aircraft performance that they would deviate from the flightpath when they initially slowed the aircraft to 250 knots, exhibiting tactical prediction and planning. However, not all participants anticipated strategically that they would need speed brakes again during the arrival in order to adhere to altitude constraints later in the path. There was an impression that using speed brakes initially should reduce the need for speed brakes later. When needing speed brakes again later in the path, 13 of 24 participants did not utilize speed brakes until the system notified them of "More Drag" (A320) or "Drag Required" (B737), and 11 of 24 participants employed speed brakes earlier than the message. Employing speed brakes earlier than automated messages implies use of estimation and prediction to anticipate effects on the path. Participants who were proactive on speed brakes did not differ by group but were distributed across groups. There were two pilots (one current A320 pilot and one 12-24 month B737 pilot) who mismanaged speed brakes, leaving them extended after the engines spooled back-up, suggesting a potential lapse in information collection, integration, estimation and prediction. These skills are noted as based on their actions and the verbal protocol, participants did not collect information regarding the recovering path (e.g., vertical deviation, predicted crossing of waypoints) and changing FMS modes and integrate this information to estimate and predict continued need of speed brakes.

Based on their application of speed brakes to stay on the path and from responses in the verbal protocol, all pilots exhibited knowledge that they were deviating vertically from the flightpath. This knowledge came different sources: from indicators on the PFD (e.g., vertical deviation symbols on altitude tape), from indicators on the ND in the B737, from the "More Drag" (A320) or "Drag Required" (B737) automated system messages, from the appropriate FMS page in the MCDU or CDU, and from assessment of whether they were going to make the altitude constraints on the path by looking at indicators in the FMS and ND and in some cases, performing calculations. For the majority of A320 and B737 participants, knowledge of vertical deviation came from the vertical deviation indicator on the PFD. However, if the aircraft deviates from the path before the pilot notices, this indicator can be hard to collect. The exact vertical deviation can be found in the MCDU in the A320 and CDU in the B737. Two 6-12 month pilots and two 12-24 month pilots “knew” this information existed but could not remember where to find it. The other pilots in these groups recalled where to find this information more quickly.

Figure 21 shows the airspeed for the A320 pilots during the arrival, separated by group. In this figure, one of the current A320 pilots had challenges at the top of descent. They accidentally hit vertical speed when attempting to enter the bottom altitude of 6000 in the flight control unit but did not realize they had enabled vertical speed. This participant then put in FL360 and briefly began to climb before updating the bottom altitude to 6000 and beginning the descent. Another of the current A320 pilots was conducting the approach briefing when they reached the top of descent and was slower to respond to ATC. Two pilots (one A320 and one B737) did exceed more than 10 kts over the speed constraints on the path at NORML after they resumed normal speeds. In the verbal protocol, these pilots commented that ATC would prefer that they made the altitude constraints over adhering to the 250 knot airspeed constraint. Therefore, they prioritized the altitude constraints and allowed the aircraft to deviate from 250.

Figure 21 also shows where airspeed differed depending on use of speed brakes. One of the A320 6-12 month pilots was slow to respond to ATC’s clearance to descend via the arrival because it took longer for them to collect the bottom altitude (other pilots had this recalled in their memory or had written it down in preparation). When receiving the 250 knot constraint from ATC, this pilot enabled speed brakes and left them on for longer even after reaching 250 knots. This meant the aircraft stayed on the path but on the lower threshold and resulted in fewer instances where the aircraft deviated from 250 knots in order to compensate for making the altitude constraints. Deviations in the speed to attempt to make the altitude constraints can be visualized in Figure 21 as well, where participants enabled speed brakes later in the path when the system notified them of “More Drag” (A320) or “Drag Required” (B737).

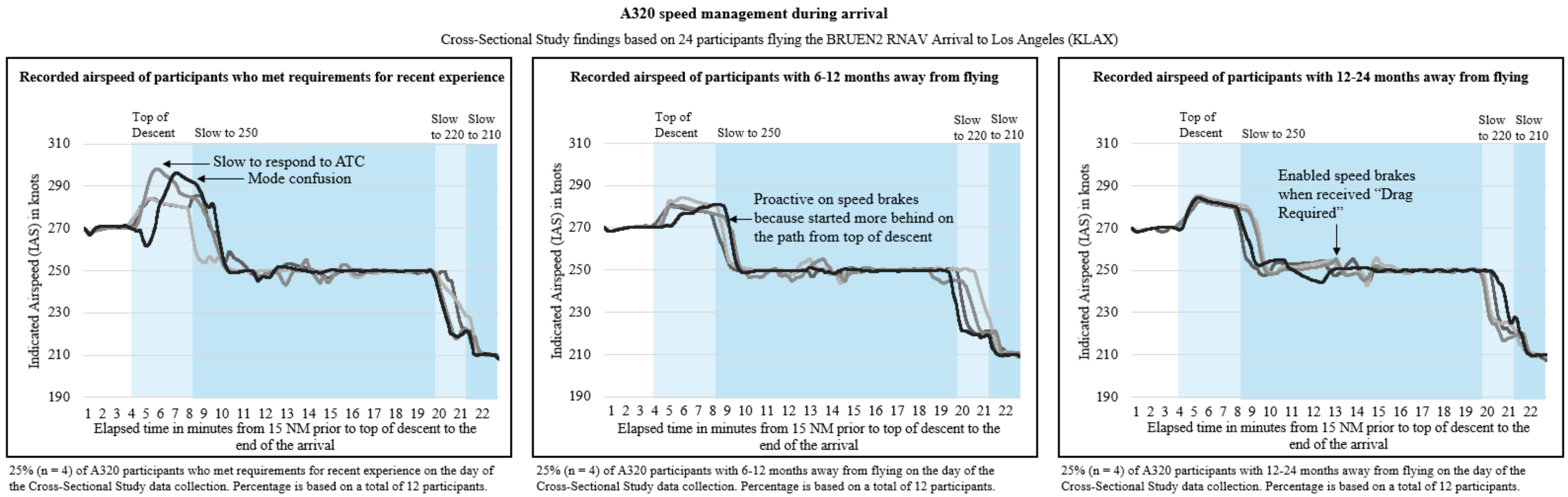


Figure 21. A320 participant's airspeed during Scenario 6, Energy Management during RNAV Arrival Descent to Los Angeles (KLAX) Navigation Source Transition during Arrival-to-Approach Operations

Participants did indicate that they were collecting, comparing, and assessing whether they would make constraints; the extent to which they completed this activity varied. Automated information is provided in both aircraft that indicates whether the aircraft will make a constraint. Two pilots relied on the information displayed on the ND only, six pilots relied on the information on the ND and provided by the FMS, ten pilots incorporated information from the aeronautical publications, and four pilots actively performed heuristics to assess whether they were going to make the next waypoint.

Assessing whether the aircraft will make the constraints at the next waypoint while also adhering to the speed constraint from ATC is a cyclical process. Participants needed, on a recurring timeframe, to do the following:

- Collect the current altitude and airspeed.
- Collect information on the next waypoint, including upcoming altitude and airspeed constraints, and any current constraints.
- Estimate the current distance and descent altitude to cross the next fix within constraints.
- Estimate based on current altitude and speed whether they will cross the next waypoint within constraints.
- Assess whether any deviations are acceptable.
- Estimate effects of systems and environment on determinations
- Adjust systems accordingly.

The frequency and effort needed to execute this cognitive process appeared to differ between groups depending on their time away from flying. Pilots who had been away from flying for 12 – 24 months tended to verbalize more both in the scenario and in the verbal protocol regarding this cognitive process. This is possibly because when a pilot is current, this activity is performed so frequently that it may be automatized. An automatic cognitive process is a mental process that is fast, efficient, and requires little conscious effort and is the result of consistent training and practice (Hammar, 2012; Sun and Zhang, 2004). The difference between the current and 12-24 month groups was with regard to how they spoke about the process. All participants were still capable of executing the cognitive process consistently enough that they met all the constraints on the path. However, when automatized cognitive skills degrade, the degradation can be observed in the speed of execution, and based on responses of the 12-24 month participants, execution of the skills listed in the bullets above may have been slightly delayed.

Longitudinal Results

Comparing the Cross-Sectional Study to the Longitudinal Study, participants exhibited more challenges in adjusting their energy management strategy and ensuring they would meet published restrictions. All participants met the constraints. However, four participants were distracted from monitoring by other tasks during the arrival (e.g., descent checklist, conversation, arrival briefing), resulting in them needing to take extra measures to ensure the aircraft stayed on the path. These were measures that they had not needed to take during the Cross-Sectional Study. For example, going off of autopilot in order to make the altitude constraints when the aircraft had deviated vertically from the path. Two pilots prioritized the altitude constraints and allowed more than 10 knots outside of the 250 constraint. Another pilot received the master caution alert for leaving the speed brakes on; they did not do this in the Cross-Sectional Study.

Scenario 7: Navigation Source Transition during Arrival-to-Approach Operations

In Scenario 7, participants used cognitive skills and knowledge to manage the aircraft through an RNAV arrival to vectors to a normal ILS approach. The verbal protocol elicited participant knowledge and cognitive skills used to manage their flightpath as they transitioned from the arrival to the approach.

Differences in responses to the verbal protocol and differences in participant actions to adjust their energy management strategy and prepare for landing are described below.

Cross-Sectional Results

All participants in all groups for both the A320 and B737 intercepted the localizer and glideslope smoothly and executed stable approaches to land at KLAX. There were differences, however, between participants in terms of when they extended flaps, deployed the gear, and how they managed airspeed as they transitioned from the arrival to vectors to the ILS. These differences do appear to align to time away from flying. Participants who were current tended to be consistent within the group regarding when they slowed to 180 and then 150 near the final approach fix and with when they extended flaps and lowered the gear during the approach. In comparison, participants who had been away from flying tended to either configure the aircraft earlier or later. Early means participants lowered the gear, slowed the aircraft to 150 knots, extended the flaps to full (or to the appropriate setting for landing), and executed the landing checklist shortly after being established on the localizer when they were 3-4 miles from the final approach fix. Participants who configured the aircraft later in the approach will have extended the flaps partially and started slowing but may not have fully extended flaps and lowered the gear until after the final approach fix and after being established on the glide slope. Some of these participants also forgot to call for the landing checklist. One A320 participant and one B737 participant who had been away from flying for 6-12 months and one A320 pilot and one B737 pilot who had been away for 12-24 months configured the aircraft earlier in the approach. Two A320 participants and one B737 participant who had been away from flying for 12-24 months completed aircraft configuration changes later in the approach, and two of these participants forgot to call for the landing checklist. In reference to calling for flaps full after passing the final approach fix, one participant told the PM, "I meant to do that a little ways back, that looks better (in referring to the airspeed tape)."

This suggests that pilots who had been away from flying may have had some knowledge degradation with respect to recalling actions they needed to complete when they needed to complete them. Participants who had been away from flying may also have been experiencing degradation of cognitive skills with respect to collecting and integrating information regarding aircraft state. Degradation of automatized skills will sometimes appear in terms of the time it takes to execute those skills. If participants were experiencing degradation in terms of time to execute skills such as collection and integration of information, this may surface as cognitive overload during phases like approach and landing, where there is a high volume of information to collect, integrate, and act on. Cognitive overload can make it challenging to focus on and retain specific knowledge and skills, such as calling for the landing checklist. In support of this, participants who had been away from flying were also less likely to mention that they were monitoring for or saw out-the-window indications such as the precision approach path indicator (PAPI) lights.

Longitudinal Results

Comparing the Cross-Sectional Study to the Longitudinal Study, ten of the eleven participants performed stable approaches while one participant executed a go-around. The participant who executed the go-around was a B737 participant who configured the aircraft later in the approach and struggled with collecting information regarding flaps. They called for a go-around upon realizing the aircraft was not configured properly. Two participants, one A320 and one B737 participant, forgot to arm the approach upon being cleared for the approach by ATC. One participant did not notice they had crossed the localizer without capturing it. To facilitate realism, ATC called to inquire and verify; at this point, the participant realized they had forgotten to arm the approach. The other participant noticed they had not armed the localizer prior to completely crossing and corrected. Two participants (one A320 and one B737) who had configured early in the Cross-Sectional Study once again configured earlier in the Longitudinal Study, meaning they lowered the gear, slowed the aircraft, extended the flaps to full (or to the appropriate setting for landing), and executed the landing checklist shortly after being established on the localizer. One of the participants who had configured early in the Cross-Sectional Study completed configurations closer to the final approach fix in the Longitudinal Study. Based on the verbal protocol where the participant indicated they normally configure earlier, this may be due to degradation, meaning they typically prefer to complete aircraft configuration as they did in the Cross-Sectional Study but were struggling with recall and slower cognitive skill execution) and so accomplished it later than they would have preferred.

Workload Assessment

Workload did not change given time away from flying for either the A320, $F(2.83, 31.12) = 0.781$, $p = .46$, $\eta_p^2=0.02$, or for the B737, $F(2.83, 31.12) = 0.253$, $p = .78$, $\eta_p^2=0.01$. Means and standard deviations are provided in Table 20 and Table 21. Regarding scale, 1-2 would be considered low workload, 3-4 would be considered moderate workload, while 5 and above would be considered high workload. None of the participants reported high workload. There is a slight trend in mental demand and effort for the 12-24 month participants that indicates they may have experienced slightly higher mental demand and effort than the participants in the current group. Generally, however, it would seem that those participants who have been away from flying are either not self-reporting high workload in this format or it is not cognitively challenging returning to flying (see Figure 22 and Figure 23). Subjective, self-report metrics such as the NASA TLX and RTLX can be challenging to elicit differences, and the sample size was small, so this result is not surprising.

Table 20. Average subjective workload (reported as means and standard deviations) collected from 12 A320 participants after each scenario for flight from Phoenix to Los Angeles.

	Mental Demand		**Physical Demand**		**Temporal Demand**		**Per-formance**		**Effort**		**Frust-ration**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Current (n=4)	3.04	1.73	1.29	0.69	2.33	1.20	2.13	1.12	2.92	1.64	1.96	0.91
Away 6-12 mo. (n=4)	2.92	2.24	1.29	1.27	2.00	1.62	2.17	1.27	2.92	2.34	1.21	1.42
Away 12-24 mo. (n=4)	3.33	1.35	1.71	0.55	2.13	1.29	2.29	0.92	3.46	1.35	1.88	0.66

"Current" refers to 25% (n=4) participants who met requirements for recent experience as defined in 14 CFR 121.439 pilot qualification for recent experience, "Away 6-12 mo." refers to 25% (n=4) participants with 6-12 months away from flying at the time of the Cross-Sectional Study, and "Away 12-24 mo." refers to 25% (n=4) participants with 12-24 months away from flying at the time of the Cross-Sectional Study. Percentages are based on 12 A320 participants.

Table 21. Average subjective workload (reported as means and standard deviations) collected from 12 B737 participants after each scenario for flight from Phoenix to Los Angeles.

	Mental Demand		**Physical Demand**		**Temporal Demand**		**Per-formance**		**Effort**		**Frust-ration**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Current (n=4)	3.25	1.78	1.92	1.02	2.88	1.70	2.33	1.24	2.92	1.56	2.33	1.37
Away 6-12 mo. (n=4)	3.50	1.79	1.50	1.01	2.08	1.59	3.17	1.69	3.17	1.83	2.67	1.48
Away 12-24 mo. (n=4)	3.46	1.62	1.67	0.83	2.21	1.02	2.33	1.86	3.58	1.59	2.13	1.71

"Current" refers to 25% (n=4) participants who met requirements for recent experience as defined in 14 CFR 121.439 pilot qualification for recent experience, "Away 6-12 mo." refers to 25% (n=4) participants with 6-12 months away from flying at the time of the Cross-Sectional Study, and "Away 12-24 mo." refers to 25% (n=4) participants with 12-24 months away from flying at the time of the Cross-Sectional Study. Percentages are based on 12 B737 participants.

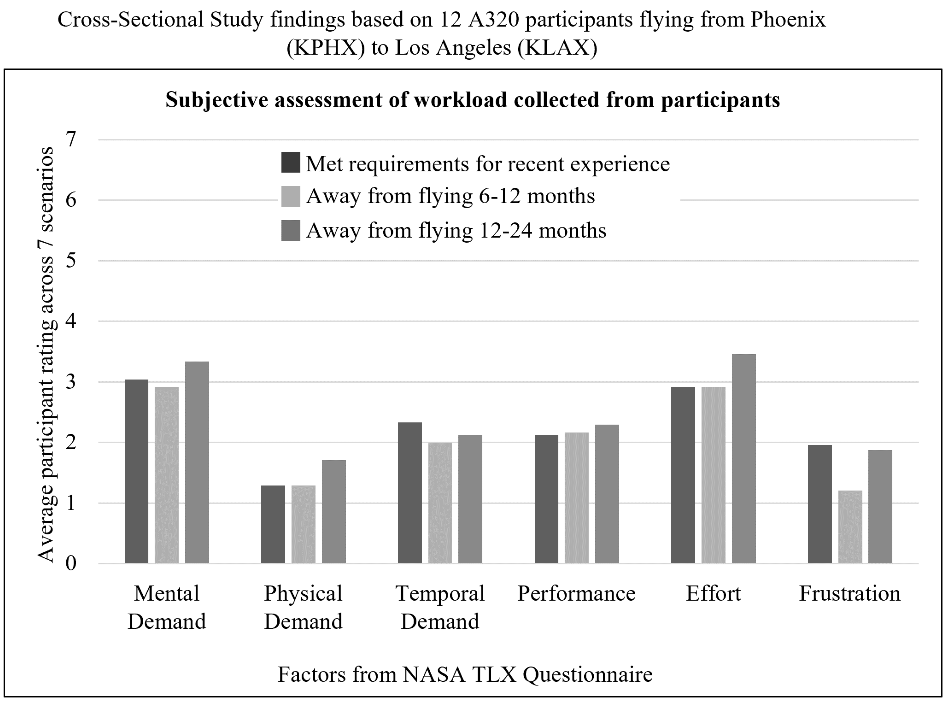


Figure 22. Average subjective workload collected from 12 A320 participants after each scenario for flight from Phoenix to Los Angeles.

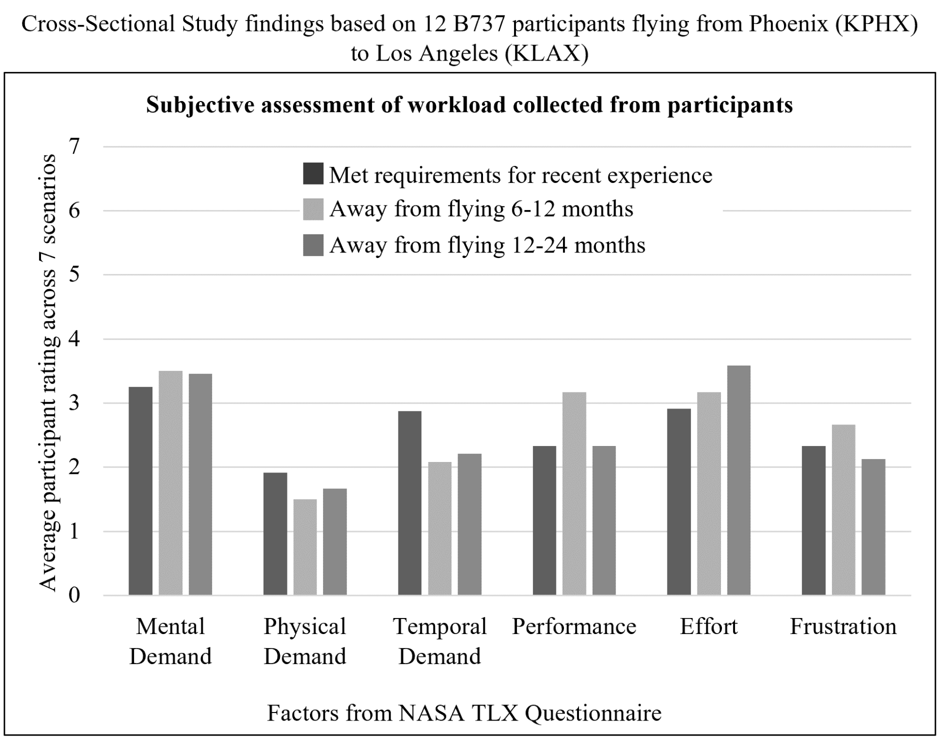


Figure 23. Average subjective workload collected from 12 B737 participants after each scenario for flight from Phoenix to Los Angeles

6. SUMMARY AND CONCLUSIONS

RQ 1: Cognitive Skills and Knowledge Susceptible to Decay and Degradation

The Cross-Sectional Study compared pilots who were current to pilots who had been away from flying for 6-12 months and for 12-24 months. Based on this comparison, the results indicate that declarative knowledge of the functions and interactions of the FMS and autoflight systems, including the flight director, autopilot, autothrottles, and flight mode annunciations are more susceptible to degradation. Declarative knowledge with regard to general airplane performance and the basic principles of flight control and engine systems remained intact. Similarly, declarative knowledge of standard flight profiles for all phases of flight was resilient, along with local knowledge, such as terrain awareness of Phoenix and traffic flow at KLAX. However, cognitive skills of collection, integration, and estimation appear susceptible to degradation. In addition, knowledge of company-specific procedures and recall of where to find relevant FPM information on ND, the FMS, PFD, and ECAM/EICAS appeared to have degraded for some participants.

The first scenario, Flight Plan Review and Assessment, highlighted the potential for knowledge degradation with regard to heuristics, such as heuristics to validate fuel and weight. There were also differences between participants in terms of review and use of the NOTAMs, where some participants thoroughly reviewed the NOTAMs and others did not. However, this did not appear to be a result of being away from flying. Similarly, differences in local knowledge of Phoenix and Los Angeles, participant assessment of weather, and knowledge of aircraft performance did not appear to be related pilot currency. There may have been some degradation with regard to the cognitive skill of collection; several participants who had been away from flying were not able to easily recollect or locate information they had reviewed in the release.

In the Longitudinal Study, three participants who had been away from flying for an additional five months noted in the follow-on evaluation that they had challenges collecting the information they needed to review the release. These same participants had not expressed feeling any challenges collecting information in the Cross-Sectional Study, further supporting that skills like information collection in the context of the flight release may be susceptible to degradation. This skill is tied to knowledge; one of the reasons participants struggled with collection was because they had challenges recalling what they would normally collect from the release when reviewing a release that had all the same information but was in a different format.

The second scenario, Pre-Flight Preparations and Flight Deck Setup, suggested declarative knowledge related to where information can be found in the FMS and flows to help guide information collection and task completion has potential to degrade with time away from flying. Participants who had been away from flying struggled to find the right pages in the FMS and locating systems and information required by checklists. Participants who had been away from flying were often able to recall what information they wanted to know, but they had challenges recalling where to find it (e.g., distance to KLAX, fuel prediction information, aircraft weight, flex or assumed temp). Degradation of knowledge may have impacted cognitive skills such as collection, integration, estimation, and planning, such as leading pilots to collect the wrong information like the top altitude from aeronautical publications and the incorrect altimeter. Participants who had been away from flying also exhibited less planning with regard to terrain, weather, and rejected takeoff considerations.

The Longitudinal Study supported that declarative knowledge related to where information can be found in the FMS and flows to help guide information collection and task completion may continue to degrade with time away from flying. In addition, participants who had additional time away from flying exhibited degradation of declarative knowledge with regard to systems like enabling terrain, enabling constraints, and for the A320, using the ND in PLAN mode.

Similar to the second scenario, results from the third scenario, RNAV Departure from Phoenix, indicated potential knowledge degradation related to recall of flows to help guide information collection and task completion. There was also evidence that knowledge of interactions between the FMS and autoflight modes may also degrade. There were differences between participants in terms of expectations about temperature, airport altitude, and terrain; these differences did not appear to be related to group differences and did not appear to be operationally relevant. Similarly, there may be some potential degradation for collection and integration of information such as airspeed and altitude, but it was unclear if this was operationally relevant.

The Longitudinal Study neither supported nor disproved degradation of knowledge or skills. The longitudinal pilots who returned were able to recall and respond adequately to manage their takeoff and initial climb with minimal consequences to the flightpath.

The fourth scenario, "Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude," indicated subtle differences between participants where those who had been away from flying executed cognitive skills of information collection, integration, and estimation at a slightly slower frequency based on adjustments to controls and responses to the verbal protocol. Participants who had been away from flying were also slightly slower (5-8 seconds) to take action after receiving the request from ATC. Participants who had been away from flying were less comfortable with changing the performance of the aircraft for a variety of reasons which included degraded knowledge,

For the Longitudinal Study, some participants chose to say unable where previously they had said yes, citing that they did not want to do the math. Of five who said yes, three did not estimate the needed rate of climb correctly. This supports potential degradation of the cognitive skill estimation.

In the fifth scenario, Managing ATC Interventions that Impact Flightpath Management (FPM) during En Route Cruise, fifty percent of the participants or 12 of the 24 participants, did not program the hold information correctly. There was not a difference between groups; it is unclear if the knowledge and skills needed to program the hold degrade due time away from flying or if this result is due to another factor. Similarly, there were differences between participants but not by group with regard to planning and prediction. Declarative knowledge related to where information can be found in the FMS did indicate potential to degrade. Similar to previous scenarios, participants who had been away from flying could often recall information they wanted to know, but sometimes struggled with finding it. There may also be degradation related to knowledge of hold execution; two pilots in the 6-12 month group held at close to their cruise speed of 270 knots.

The Longitudinal study did not provide support for degradation due to time away from flying. Some participants took longer in the follow-on evaluation to find the information they needed to make estimations and inform their decision making and planning, supporting cross-sectional finding regarding knowledge gaps in using information systems to support planning. This included participants who were able to program the hold correctly, suggesting there is not necessarily a relationship between collecting and integrating the information to program the hold and collecting and integrating the information to develop a plan for holding.

The sixth scenario, Energy Management during RNAV Arrival Descent to Los Angeles, highlighted differences between participants with collection of information regarding their vertical flightpath and potential deviation, and the degree to which they estimated and then predicted the need for speed brakes to stay on the path. Participants appeared to collect, compare, and assess whether they would make constraints; the extent to which they completed this activity varied. The frequency and effort needed to execute this cognitive process appeared to differ between groups depending on their time away from flying. The difference in frequency and effort did not affect ability to make constraints; all participants employed speed brakes and were able to manage their path to make constraints. Employing speed brakes earlier than automated messages implies use of estimation and prediction to anticipate effects on the path; there were not obvious group differences between pilots in terms of estimation and prediction. There were two pilots (one current A320 pilot and one 12-24 month B737 pilot) who mismanaged speed brakes, leaving them extended after the engines spooled back-up, suggesting a potential lapse in information collection, integration, estimation and prediction.

In the Longitudinal Study, four participants were distracted from monitoring by other tasks during the arrival (e.g., descent checklist, conversation, arrival briefing), resulting in them needing to take extra measures to ensure the aircraft stayed on the path. Effort needed to collect, compare, and assess whether they would make constraints appeared to increase, but all participants were still able to manage their path effectively.

Scenario 7, Navigation Source Transition during Arrival-to-Approach Operations, supports potential degradation of where information can be found in the FMS and flows to help guide information collection and task completion has potential to degrade with time away from flying. There were differences in how participants transitioned from the arrival to the approach and configured the aircraft for landing. Participants who had been away from flying had more challenges recalling actions they needed to complete when they needed to complete them.

Overall, the degradation of knowledge and skill appears distinct yet interrelated. Knowledge may degrade more than the cognitive skill that uses that knowledge, and this directly impacts the ability to execute the cognitive skill. For example, in Scenario 4, one of the pilots recalled that they could slow to expedite the climb, but they did not recall to what speed it was safe enough to slow down to, and so was unable to make ATC's request. Conversely, skills may degrade more than knowledge; a pilot might know they need to perform a certain action but fail to execute it properly due to degraded skills. For example, a pilot might know they should be more actively estimating and evaluating whether they will make the constraints at the next waypoint, and they may know heuristics to perform the estimation. However, executing the estimation to calculate the distance or result of the heuristic requires cognitive skill that has degraded.

Regarding declarative knowledge, several areas showed degradation. This includes knowledge of the functions and interactions of the FMS and autoflight systems, including the flight director, autopilot, autothrottles, and flight mode annunciations. Specifically, pilots in the 12-24 month group were more likely to engage autoflight systems in the wrong mode, could not recall how to engage the automation mode they wanted, and had challenges recalling knowledge pertaining to the functions and interactions of the FMS. Pilots also showed diminished recall of detailed procedures and performance specifics as outlined in company training and aircraft manuals. Pilots in the 12-24 month group either took longer to try recall the information they needed to perform correct procedures, or they skipped it (e.g., not briefing particular topics). Even with checklists they were familiar with, 12-24 month pilots found it harder to recall and verify systems, settings, and information on the flight deck. Most declarative knowledge with regard to general airplane performance and the basic principles of flight control and engine systems remained intact, with some specific knowledge gaps which may have pertained more to initial baseline proficiency than pure degradation.

Declarative knowledge of standard flight profiles for all phases of flight appeared to be less degraded, along with local knowledge, such as terrain awareness and normal operational procedures. Pilots who had flown frequently (i.e., more than once a month) out of Los Angeles or Phoenix recalled taxi-way routes, special engine out procedures, runway operations, and other local knowledge with relative ease. Prior research suggests that proceduralized skills are more resistant to degradation. However, this study found that even these skills deteriorate, as actions that should be quick and instinctual for current pilots require more thought and time for those who are not current, due to gaps in knowledge and memory.

In terms of procedural knowledge, there was noticeable degradation in company-specific procedures and the ability to use systems to manage flightpath changes effectively. Pilots struggled with recalling where to find relevant FPM information on ND, the FMS, PFD, and ECAM/EICAS. Although pilots retained their general aviation schemas and principles, such as the effects of weight, atmosphere, and weather patterns on performance, their ability to quickly recall specific ranges and apply this information effectively was impaired. This suggests that while the foundational knowledge remains, the ability to use it efficiently in practice may have degraded.

RQ 2: Potential Causes of Decay and Degradation

Across the analyses, there were examples of gaps in knowledge and skills. However, these gaps were not always differentiable by pilot group, meaning the potential degradation in skill and decay in knowledge was not strictly due to time away from flying. Degradation in aviation skills and knowledge can be influenced by more than just time away from flying. While it's evident that time away from the flight deck can contribute to degradation of cognitive skills and knowledge, other factors also play a role. One of the primary factors is the initial baseline proficiency. The degree to which a skill is initially trained and how it is maintained over time are pivotal in determining the extent of degradation. For example, the Longitudinal Study supported that declarative knowledge such as knowledge of the functions and interactions of the FMS and autoflight systems continues to degrade with time away from flying; however, based on participant responses to Scenario 5, time away from flying may not be the factor contributing to degradation of the knowledge and skills needed for executing a hold.

In some instances, it is possible degradation of knowledge and skills may be the result of rigidity that occurs from automatized skills. Automatization occurs naturally as a means to reduce mental processing and speed up execution of frequent and repetitive tasks. Automatization allows for less dependence on recalling task specific knowledge, but because of automatization, the knowledge for the task becomes less called upon. This can result in the knowledge degrading over time, which can then present challenges when attempting to translate automatized skills to new tasks. For example, the results from this study found that the flight release was in a different format than the pilots were used to. Some pilots (both current and not current) commented that they found it challenging to collect information they needed such as the weight, fuel, passenger loading, alternate information, weather, and ATIS from the release when faced with a new layout. Some participants exhibited difficultly recalling what they needed to find in order to adequately review the release. This indicates a degradation of knowledge where they could not recall the information they needed to collect. For participants who had been away from flying, this challenge could just be due to time away. However, for participants who were current, this may be due to automatization of their review of the release, where they needed to recall specific knowledge to maintain the flow of the task in a new format, and they had challenges recalling that knowledge due to automatization. While these challenges were by no means insurmountable and did not result in serious errors, this does highlight how (1) staying consistently with one way of executing tasks (i.e., task automatization) can lead to potential degradation in knowledge and (2) how struggling with new technology may indicate skill or knowledge degradation or decay.

Stress and cognitive overload may be an indicator of decay and degradation, particularly when pilots exhibit difficulties maintaining awareness and retaining specific knowledge and skills. While there were no significant differences in reported workload, the 12-24 month pilots engaged in 64% less social dialogue than current pilots when comparing all 24 participants' communications (see Appendix N). One reason for this might be that they were mildly overloaded or conscious of their own decreased task performance in comparison to the current pilots, and the subsequent stress resulted in a decrease in pro-social behavior.

One 12-24 month pilot's statement confirmed this, where they said to their PM, "It's not normally this awkward silence that it is now, but just by virtue of it being so different and unfamiliar, I'm just kinda trying to…". In this case, the overload was making it challenging to execute the skills and knowledge that he needed to.

Finally, psychological factors such as stress and over confidence may contribute to knowledge and skill decay. High-stress situations can negatively impact a pilot's ability to perform and recall procedures accurately. Over time, repeated exposure to stress without adequate coping mechanisms can lead to further degradation. Conversely, a lack of challenging situations or a high degree of competency can lead to complacency, where pilots become overconfident and fail to maintain a high level of vigilance and proficiency. In the latter case, there were several pilots who possessed a high level of confidence but exhibited gaps in knowledge. One 12-24 month pilot commented that they realized they "had the comfort and confidence but not the performance. It's all familiar but… I don't remember things…"

RQ 3: Potential Mitigations for Cognitive Skill and Knowledge Degradation

There is of course no substitute for practice. Practicing a skill regularly is a fundamental approach to mitigating degradation, as it reinforces the mental associations with that skill, enhancing both muscle memory and cognitive recall. Frequent practice ensures that the skill remains sharp, allowing the individual to perform it with precision and confidence even under pressure. Over just the course of the seven scenarios in this study, recall of knowledge improved for the pilots in the 6-12 and 12-24 month groups who in Scenarios 1, 2, and 3 had challenges collecting and recalling information that they needed to review the flight plan, prepare the flight deck, and execute the takeoff. As participants adjusted and settled back into the context of the simulator and flying, recall improved. Memory had still decayed, but recall was slightly less challenging. This suggests continual reinforcement is helpful to prevent the erosion of both procedural and declarative knowledge and ensure skills remain intact. With the knowledge and memory items that decayed, focused review might suffice to maintain ability to recall. With the skills that degraded, practice in context would reinforce the mental associations, and keep the skill current.

Encouraging pilots to regularly evaluate their own proficiency may be another method for mitigating cognitive skill and knowledge degradation. Self-assessment can help pilots identify areas that need improvement before they become issues. However, based on the verbal protocol employed in this study and the ability to compare what pilots said they did versus what they actually did, there were some pilots who exhibited discrepancies in their perspective (i.e., what they think they did) and reality (i.e., what they actually did). Self-assessment as a skill would need to be taught, so individuals can accurately perceive their performance. This could be facilitated through structured self-assessment tools such as structured video replay, questionnaires, and debriefing that allow pilots to reflect on their recent performances and identify specific knowledge gaps or skill deficiencies. However, training self-assessment may not necessarily lead to proactive self-assessment. Other research has indicated an environment encouraging continuous learning and professional development is also important for proactive self-assessment (Shufutinsky & Long, 2017). Formal recurrent training with proactive self-assessment combined with an environment encouraging proactive self-assessment may mitigate degradation.

Limitations

There are several risks, limitations, and assumptions to the design of the study performed. These include:

<u>Aircraft and Operations Assumptions and Limitations</u>

- Limitation & Assumption: Flightpath data and flight deck dependent data such as systems interactions from the Airbus A320 and Boeing 737 cannot be compared directly. However, a collection of themes and insights across them can be identified and documented.

- Assumption: A fixed-based Boeing 737 simulator and Airbus A320 FTD are acceptable platforms for collecting data about cognitive skill and knowledge degradation.
- Assumption & Risk: The differences between a Level D equivalent A320 simulator and an A320 flight training device (FTD) (e.g., using an A320 aerodynamics package to convert simulator performance to that of an A320) will not negatively impact the research and corresponding data.
- Assumption & Risk: The A330 flight deck will not negatively impact the research and corresponding data.
- Assumption & Risk: The differences between a B737 FTD and a B737 research-based simulator will not negatively impact the research and corresponding data.
- Limitation: This research is limited to current flight operations that are conducted under 14 CFR Part 121 and 135 in a transport category aircraft.

Methodology Limitations and Risks

- Assumption & Risk: Starting and stopping the simulation at defined points-in-time to administer a verbal protocol poses a risk to the cognitive processing of the participants and their mental models of the flight. Assumption is the verbal protocol will not negatively impact participants cognitive processing.
- Assumption & Risk: Administering a verbal protocol will not appreciably impact a participant's mental model. Participants' will not be influenced by the verbal protocol and adapt their mental model as a result, modifying how they might perform in later scenarios.
- Limitation: Research does not address all cognitive skills and knowledge necessary for FPM tasks. For example, knowledge of standard, company-specific actions and callouts was challenging to assess directly, without a confederate PM from the company. Knowledge of functions and operations of the weather radar, TCAS/ADS-B, and EGPWS equipment, as described in the appropriate company and aircraft manuals, and training, was not explored in this study. Finally, the scenarios and analysis were designed to assess six primary cognitive skills. However, more than six cognitive skills are described in the inventory and can be necessary for FPM.
- Assumption: Evaluating pilot interactions with information automation (IA) systems can provide insight into cognitive skill decay and degradation.
- Assumption: Working with a confederate PM and having different perspectives on operational procedures does not severely disrupt exhibited skills and knowledge.
- Assumption: Despite the operational complexity, it is possible to provide a research basis for identifying factors that contribute to the decay and degradation of cognitive skills and knowledge necessary for certain FPM tasks, and the degree to which it impacts differences in performance for groups of participants who have been away from flying for different periods of time.
- Risk: Participants who returned for the Longitudinal Study recalled previous participation.
- Assumption & Risk: Participants will not treat the study as realistically as they would an operational environment.
- Limitation: Aircraft system failures and malfunctions are not within the research scope.
- Risk: Stating that degradation exists when results were due to chance and that it does not actually exist within the context of this research study. Similarly, stating that degradation does not exist when it does exist within the context of this research study.
- Limitation & Risk: The sample size for the study may not be representative.

Conclusions

This research highlights the importance of cognitive skills and knowledge among commercial pilots. The study results demonstrates that skill degradation is influenced by various factors, including time away from flying. The findings underscore the need for robust recurrent training programs that incorporate both theoretical and practical elements to ensure pilots remain proficient. Additionally, leveraging modern simulation technologies and implementing structured self-assessment tools may help mitigate the effects of knowledge and skill decay. By addressing these factors, the aviation industry can enhance pilot performance and support safety and efficiency in increasingly complex operational environments.

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APPENDIX A – COGNITIVE SKILLS INVENTORY

HON_CognitiveSkillsInventory.xlsx

The Cognitive Skills Inventory documents a set of flightpath management objectives, associated flightpath management cognitive tasks, flightpath management cognitive skills, and examples of supporting flightpath management knowledge.

When reading the inventory, there are a two important points to keep in mind:

> First, the tasks and the cognitive skills and knowledge needed to support those tasks are executed in a cyclical and continuous manner. While the tasks, skills, and knowledge are listed in the inventory sequentially, they are not necessarily performed sequentially or linearly, and they are repeated very frequently throughout a flight. When reading the inventory, you will likely read it in a linear or sequential fashion, but keep in mind that this may not be how the tasks, skills, and knowledge are actually executed.
>
> Second, this inventory was drafted by considering a particular context, which was a single flight from Atlanta to Boston, on a clear sky day, with minimal traffic. Details about the context for each phase of flight is described in the inventory and is important to keep in mind when considering skills and knowledge for other potential contexts.

The inventory is contained in an excel spreadsheet which consists of eleven tabs. The "Inventory" tab, which is the 7th tab in the spreadsheet, provides the FPM objectives, tasks, skills, and knowledge in the context of a single flight. The other tabs contained in the excel should be used to support one's reading of the overall inventory on Tab 7. Tabs are color coded to provide general guidance on how the tabs relate to one another. Tabs in light green provide smaller segments of the objectives, tasks, skills, and knowledge that are in the "Inventory (Tab 7)" as additional ways to read and process this information. Tabs in light blue provide supplementary information related to the inventory, such as charts for the flight context.

A brief overview of the contents of each tab and the intended use of each tab is described below.

Tab 1 – Important Information

This tab contains version tracking information, recommendations for reviewing the inventory, a description of the contents, definitions that are useful to know when reviewing the inventory, acronyms used in the inventory, and shorthand used to refer to different phases of flight.

Use this tab as a reference when reviewing the inventory to understand the contents, including cognitive terminology and acronyms.

Tab 2 – FPM Task Objectives

This tab details the flightpath management objectives and provides a chart that indicates for which phases of flight each objective is relevant.

Use this tab to view FPM objectives independently of tasks, skills, and knowledge.

Tab 3 – FPM Cognitive Tasks

This tab details the cognitive tasks to be performed for each flightpath management objective.

Use this tab to view the FPM cognitive tasks independently of cognitive skills and knowledge.

Tab 4 – FPM Cognitive Skills

This tab provides a list of the cognitive skills used to complete the cognitive tasks associated with the different flightpath management objectives.

Use this tab to view the FPM cognitive skills in context of cognitive tasks and objectives, independently of phases of flight.

Tab 5 – FPM Knowledge

Examples of knowledge that supports the flightpath management objectives, cognitive tasks, and cognitive skills are provided in this tab.

Use this tab to view examples of the FPM knowledge independently of flightpath management objectives, cognitive tasks, and cognitive skills.

Tab 6 – Context for Inventory

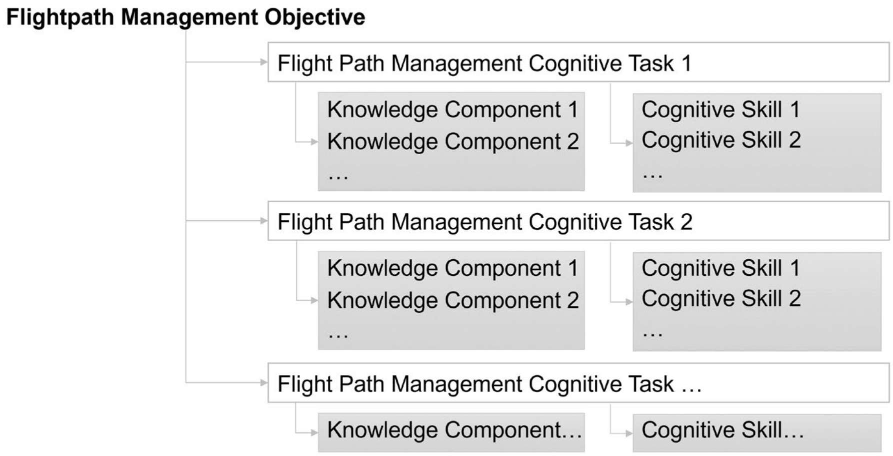
As mentioned, the inventory was developed based on a single flight from Atlanta to Boston on a clear sky day with minimal traffic. The conditions, environment, and example activity for each phase of flight is detailed in this tab.

Use this tab to view conditions, environment, and example activity for each phase flight in condensed view.

Tab 7 – Inventory

This tab combines Tabs 2 through 6 to provide an inventory of FPM task objectives, FPM cognitive tasks, FPM cognitive skills, and FPM knowledge across a single flight, by phase of flight. This tab also lists current information systems and sources needed to perform the FPM cognitive tasks and high-level descriptions of how the information sources and systems would be used to perform the cognitive tasks. A brief description of how a system like Controller-Pilot Data Link Communications (CPDLC might affect cognitive skills and knowledge is also included. Finally, skills that are potentially at-risk of degradation and why, and how skills and knowledge may differ in implementation if the pilot monitoring is executing the skill are called out.

To use this tab, you first understand need to recall that the inventory is hierarchal. For every FPM objective, there is a set of cognitive tasks, and for each cognitive task, there is a set of knowledge components and cognitive skills, as shown in the figure below:



With this hierarchy in mind, note that every row in the Inventory tab is for a specific cognitive skill, which are detailed in Column J. Reading the inventory from left to right:

- Columns A and B refer to the phase of flight. Column A is the phase of flight ID, shorthand for the full name of the phase of flight contained in Column B. The shorthand identifier can be used to for reference to know which phase of flight the current row is mapped to as you scroll further to the right in the spreadsheet.
- Column C contains the context description for the phase of flight, which can also be found in Tab 6 – Context for Inventory. The context description is for the whole phase of flight. It covers multiple rows, as there are multiple objectives, tasks, knowledge components, and skills within a single phase of flight.
- Column D contains the FPM Task Objective. This objective covers multiple rows, as there are multiple tasks, skills, and knowledge components associated with each objective.
- Column E contains the cognitive task and Column F provides a brief description of the cognitive task, which can also be found in Tab 3 – FPM Cognitive Tasks. Again, the cognitive task covers multiple rows, as there are multiple knowledge components and skills associated with a cognitive task.
- Columns G and H provide breakdowns of the information systems and sources for the cognitive task and how those information sources and systems may be used.
- Column I contains examples of the knowledge used to perform the FPM cognitive task described in Column E.
- Column J breaks down all the cognitive skills used to perform the FPM cognitive task and Column K provides a brief description of each cognitive skill.
- Column L and Column M provide a description of how a system like CPDLC could affect cognitive skills and knowledge, where applicable. N/A means the system would not apply or was not considered to apply to that row (e.g., phase of flight -> FPM objective -> FPM task -> knowledge component -> cognitive skill).
- Column N details if a skill is at-risk and why.
- Column O details potential differences for the pilot monitoring at the level of the FPM task objective.

As mentioned, when reading this tab, it is important to note that tasks would be completed more than once, in a cyclical fashion. For example, the cognitive task of "Identify the aircraft's actual lateral position, actual vertical position, and actual energy state" would be a recurring task executed constantly. The knowledge and skills associated with accomplishing that task would also be used constantly.

Tab 8 – Charts for Context

This tab provides the aeronautical publications used to develop the inventory with subject matter expert pilots.

Use this tab as supplementary information to support understanding of the context described in Tab 6 and the work to develop this inventory with subject matter experts.

Tab 9 – List of Cognitive Skills

This tab contains a reference to a larger list of cognitive skills documented in prior work and provides a general description of each cognitive skill.

Use this tab as supplementary information to support understanding of the cognitive skills referenced in the rest of the document.

Meta-Cognitive Skills (Tab 10)

This tab provides a list and description for relevant meta-cognitive skills used for flightpath management and captured during subject matter expert review of the inventory.

Use this tab as supplementary information to support understanding of the skills for flightpath management.

Sample Criterion for At-Risk Skills (Tab 11)

Describes sample criterion for informing determining which skills are most at risk for degradation.

Use this tab as supplementary information for understanding potential at-risk skills.

APPENDIX B – EXPERIMENTAL PROTOCOL

High-level Protocol

Total Time: 244 minutes

Time (min)	Experimenter / Team Actions
----	Make sure simulator on, ensure flight plan is loaded and available, weather is configured / programmed, cameras are turned on and recording, audio is prepared, tablet for questionnaires is prepared, water available. Ensure all defaults are set in the simulator.
15 min	Welcome participant & give an introduction. Describe the study and why they are here in more detail. Provide a safety briefing and overview of the sim. Explain participant role as pilot flying and pilot-in-command. Provide general checklist. Provide an overview of the verbal protocol and an example of how this will work. Fill out consent form.
10 min	Scenario #0: Flight Plan Review and Assessment.
15 min	Scenario #0: Verbal protocol.
10 min	Provide a break; make way to simulator.
10 min	Scenario #1: Pre-flight Preparations and Flight Deck Setup
10 min	Scenario #1: Verbal protocol.
7 min	Scenario #2: Area Navigation (RNAV) Departure from Phoenix (KPHX)
10 min	Scenario #2: Verbal protocol.
14 min	Scenario #3: Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude
20 min	Scenario #3: Verbal protocol.
20 min	Scenario #4: Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise
15 min	Scenario #4: Verbal protocol.
28 min	Scenario #5 and #6 • 5 - Energy Management during RNAV Arrival Descent to Los Angeles (KLAX) • 6 - Navigation Source Transition during Arrival-to-Approach Operations
20 min	Scenario #5,6: Verbal protocol.
10 min	Provide a break; make way out of simulator.
10 min	Questionnaire
20 min	Debrief

Participant Introduction

Below to be covered with Briefing Presentation:
Welcome! Thank you for helping Honeywell and FAA with this study. If you have any questions as we go through this briefing, feel free to stop us and ask questions anytime.

We appreciate you lending us your expertise! Your participation will help Honeywell provide input to help the FAA develop future policy and pilot training guidance. Note - Honeywell is not the FAA. We are a performer on a research program, funded in-part by the FAA, to help the FAA develop future policy and pilot training guidance.

General Information
All of your information will be deidentified. Your participation in this study is anonymous. No names will be collected; all data files will have a participant number only. Everything we are collecting within this study is for research only, not for training or evaluation.

What do you need to do?
- Review and sign the informed consent document.
- Participate in the study briefing.
- Fly seven scenarios in the seat you were last certificated for
- We want to observe flight operations as you would fly on the line as much as possible!
- You will be the Pilot Flying (PF)
- You may transfer control to the PM when you decide it is appropriate.
- After each scenario, I am going to ask you a set of questions. Please try to answer my questions throughout the scenarios to the best of your ability. I myself am NOT a pilot so couple things… (1) if you don't understand what I'm asking about, please ask me to clarify, and (2) I'm not a pilot! So, try to give me as much detail as you can.
- Participate in the debriefing.
- Complete a questionnaire.

For Each Scenario
- We want to observe flight operations as you would on the line as much as possible.
- You will get information before each scenario starts to help you understand where you are geographically and situationally.
- You will have as much time as you need to get prepared and ready to go from the position where the scenario will start.
- For example, if you would have completed a briefing or programming before the point in time that the scenario starts, we will give you time to brief and would like you to take that time, confirm the programming is done to your liking, before you say you are ready to go.
- Do all briefings and call for checklists as if you were flying a normal line trip.
- Fly and communicate with the PM as you would on the line (however, realize that that the PM will not be proactive).
- After landing, bring the aircraft to a full-stop on the runway.

What Information Are We Collecting?
- Aircraft state data from the simulator
- Video data
- Audio data
- Questionnaire data

All data will be analyzed and reported in aggregate. Your name will NOT be linked to any data collected today.

Participant Materials:

- Consent form
- Release with Performance Data
- Aeronautical Publications (Jeppesen)
- Checklists
- Scenario Location Start Images
- Questionnaires

Make sure to have participant:

☐ Sign Consent Form

Scenario 1 – Flight Plan Review and Assessment

Scenario start:

Participant receives the flight release in the briefing room (this scenario will be recorded).

Scenario stop:

Participant verbally states they have reviewed the release and are ready to proceed to the simulator flight deck.

Experimenter:

☐ Turn-on video and audio recording.
☐ Hand participant release, paper charts, and EFB.

This is a release for a flight from Phoenix to Los Angeles for the flight you will be conducting in the simulator today. Here is an EFB with the aeronautical publications as well as a paper copy. Please review the release. When you are done reviewing the release, please state when you are done and ready to proceed to the simulator flight deck.

☐ Begin timer when start reviewing release.
☐ End timer when stop reviewing release.
☐ Have participant fill out NASA TLX.

During Scenario:

Where possible, mark observations

Observations	Notes (In the moment)
Did the participant look at every page of the provided release?	
Did the participant look at aeronautical publications?	
Did the participant use electronic or paper for aeronautical publications?	
Did the participant make any requests for information?	
Do they go back and forth between release and aeronautical publications?	

Do they ask for any additional information regarding fuel, weight, or weather?	
Do they request or mention more fuel?	
Did they mark up the aeronautical publications (e.g., marking taxi route)?	
Did the participant make other notes?	
Did they talk about the release out loud?	
Did they make any requests of additional information or changes to the release?	

Verbal Protocol:
Check off as ask each question.

- ☐ Did you have any challenges collecting information from this flight release?
- ☐ Do you prefer paper or electronic information when reviewing a flight release and a flight plan?
- ☐ Does the type of media impact how you collect and annotate information?
- ☐ What knowledge about aircraft performance did you leverage when reviewing the flight release?
- ☐ What NOTAMs are applicable to the route of flight, and why?
- ☐ What operational experience do you have at Phoenix? Based on this experience were their other things you considered?
- ☐ What operational experience do you have at Los Angeles? Based on this experience were their other things you considered?
- ☐ How did you determine if the information a dispatcher provided in this flight release is an accurate reflection of what is needed to complete the flight?
    - Fuel
    - Weight
    - Performance
    - Weather
- ☐ What is the minimum information you need to review in order to develop a mental model of the flight before it occurs?
- ☐ What information from the flight release did you prioritize from most important to least important, and why?
- ☐ Are there any NOTAMs that might impact this flight?
- ☐ Is there information missing from this flight release? If yes, what information is needed and from what source?
- ☐ Did you make any notes as you reviewed the release? If yes, what notes did you make?
- ☐ Did you make any notes as you reviewed the aeronautical publications? If yes, what notes did you make and why?
- ☐ Is there any information you would provide or receive from dispatch prior to a pre-briefing?
- ☐ What information would you emphasize during your pre-brief with another crewmember?

Scenario 2 – Pre-flight Preparations and Flight Deck Setup

Scenario start: Aircraft is at gate A7 at KPHX.
Scenario stop: Pre-flight briefing complete.

Experimenter:

- ☐ Hand participant the checklists.

    For the scenarios, we're going to use these checklists. I'd like you to take a minute to take a quick look through them and familiarize yourself with them. Please let me know when you are done.
- ☐ Take short break.
- ☐ Direct the participant to the simulator and direct them to the right/left seat depending on if Captain or FO.

- ☐ Tell the Control Room to load Scenario 2.
- ☐ Confirm recording has started.
- ☐ Once the participant is comfortable, instruct them that…
  The aircraft is parked at gate A7 in Phoenix. We would like you to accomplish and verify everything that any pilot would have been doing at the gate. Some of the tasks on the preflight checklist will already have been done so those would be verifying. For example, you have already done your walk-around. You have already talked to flight data, and you are cleared to Los Angeles International Airport, as filed, climb via the SID, expect FL340 10 minutes after departure, departure frequency 126.8, Squawk 5636. Also, the engines are already on, but you can act like you are on ground power. Once you reach the point where you would be ready to taxi but have not done the taxi checklist, please let me know and we will pause there.
- ☐ Provide participant with written clearance.
  - Cleared to KLAX climb via KEENS2 MESSI transition expect FL340 10 minutes after departure. Departure frequency 126.8. Squawk 5636.
- ☐ Have participant fill out NASA TLX.

During Scenario:
Where possible, mark observations

Observations	Notes (In the moment)
Did the participant look at INIT, F-PLN, SEC F-PLAN, Radio NAV, FUEL PRED, PERF TAKEOFF?	
Did participant enable CSTR?	
Did participant enable TERR?	
Did participant enter PLAN mode in ND ?	
Scroll through F-PLN while checking ND?	
Did the participant reference the release while checking the loaded plan?	
Did the participant check charts while checking the loaded plan?	
Did the participant dial in 8000 ft into altitude selector?	
Do they ask for any additional info regarding fuel, weight, or weather?	
Did the participant mention fuel, weight, performance, terrain or weather within the context of potential effects on the flight?	
Did they brief terrain?	
Did they brief weather?	
Did they request or mention more/or less fuel?	
Did they talk about when they are going to enable autoflight?	
Did the participant follow briefing checklist or do their own version?	
Did the participant ask the PM for their perspective on threats?	
Did the participant discuss expectations for the takeoff and departure beyond basic details?	
Did the participant discuss expectations for the flight overall?	

Verbal Protocol:
Check off as ask each question.

- ☐ Going from the pre-brief to here, did you have any issues finding or recalling information you needed to review the loaded flight plan?
- ☐ Did you have any issues finding or recalling information you needed to brief the departure?

- ☐ How did you utilize knowledge, like techniques, rules of thumb, and other resources at your disposal with flight deck displays to confirm the loaded flight plan?
- ☐ How did you utilize knowledge, like techniques, rules of thumb, and other resources at your disposal with flight deck displays to brief the departure?
- ☐ How did you determine if the loaded flight plan was accurate?
- ☐ What information is helping you develop a mental model of the flight before it occurs?
- ☐ You [did/did not] brief terrain. How [was/was not] terrain a factor?
- ☐ You [did/did not] brief weather. How [was/was not] weather a factor?
- ☐ You [did/did not] brief when you were going to enable autoflight. Can you tell me why you [did/did not] brief it and why?
- ☐ Utilized ND: I noticed you used/did not use the ND to review the flight. Can you tell me why?
- ☐ CSTR Enabled: I noticed you had/did not have CSTR enabled. Can you tell me why?
- ☐ I noticed that you [used/did not use] the briefing checklist. Can you tell me why?
- ☐ I noticed that you [did/did not] ask your PM about threats. Can you tell me why?
- ☐ What other information would you expect to receive that you have not?

Scenario 3 – Area Navigation (RNAV) Departure from Phoenix (KPHX)

Scenario start: Holding short of KPHX RW 7L.
Scenario stop: One minute after passing through 8000 ft.

Experimenter

- ☐ Tell the Control Room to load Scenario 3.
- ☐ Once Scenario 3 loads…
  We stopped at the point where you were ready to taxi, when we were still parked at A7. We are not actually going to taxi to the runway, we would like you to just know that you did taxi to the runway. We are currently holding short of runway 7L. When we stopped, you had not conducted the taxi checklist. We would like you to start with the taxi checklist now.
- ☐ Tell Control Room to start Scenario 3.
- ☐ After 8000, time for one minute. Tell the Control Room to stop Scenario 3.
- ☐ Have participant fill out NASA TLX.

During Scenario:

Where possible, mark observations

Observations	Notes (In the moment)
Did they reference the EFB?	
What information was displayed on the EFB?	
Did they the enable CSTR?	
Did they the enable TERR?	
What pages did they have showing on the FMS?	
Did they make a request to ATC for information?	
If they made a request to ATC for more information, what kind of request did they make?	
When did they participant make their request to ATC?	

When did participant complete aircraft configuration changes?	
When did participant engage autoflight systems?	
Callouts related to establishing targets for airspeed, altitude, thrust, and trajectory (tactical planning based on changing situation)	
Did the participant clearly communicate with the PM?	
Did the participant ask the PM for help? If yes, what kind of help?	
What information did the participant collect from their PM? From ATC	

Verbal Protocol
Check off as ask each question.

- ☐ What airspeed, altitude, and heading indications did you monitor during…
    - takeoff roll
    - initial climb
    - established climb.
    - level-off (if they did not request higher)
- ☐ Why or why not?
- ☐ Which airspeed, altitude, and heading indications do you prioritize during…
    - takeoff roll
    - initial climb
    - established climb.
    - level-off (if they did not request higher)
- ☐ Why or why not?
- ☐ Was there anything else you were looking at?
- ☐ Why or why not?
- ☐ Were you looking at anything on the FMS? Why? What does it mean?
- ☐ Did you use the EFB?
- ☐ How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath and energy state during:
    - takeoff roll
    - initial climb
    - established climb.
    - level-off (if they did not request higher)
- ☐ Did you estimate the effects of hot weather or high-altitude on your performance? Why or why not? [if yes, how]
- ☐ You mentioned using [airspeed, altitude, heading indications] to monitor your climb performance. Can you elaborate on how you used these [indications]?
- ☐ Did you consider the flex temp at takeoff?
- ☐ Why did you choose to engage autoflight systems when you did?
- ☐ Why did you choose to complete aircraft configuration changes when you did?
- ☐ When did you realize you should ask ATC about continuing the departure climb?
- ☐ How did you verify that the performance of the aircraft was what you were expecting to get in regard to:
    - vertical flightpath
    - lateral flightpath
    - speed during the departure.
- ☐ Were you anticipating any changes to the departure that could affect the performance? Why or why not?
- ☐ What information did you use to make decisions to:
    - Engage autoflight systems.
    - Complete aircraft configuration changes
    - Query ATC about continuing the departure climb.
- ☐ What was the basis for the callouts you made?

Scenario 4 – Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude

Scenario start: On KEENS2 departure 16,660 between WILKO and KEENS
Scenario stop:
(1) Said yes to ATC, stop 2 minutes past FL320.
(2) Said no to ATC, stay at FL300 for 1 minute, then cleared to FL320, stop when reach FL320.

Experimenter

- ☐ Tell the Control Room to load Scenario 4
- ☐ As Scenario 4 loads…
  We stopped while we were climbing, and you had just passed MASVE. You were cleared to FL220. We going to resume the flight, and you are still climbing, you are still on the KEENS2 departure and talking to departure control. You are at 16,660 near the KEENS waypoint. Please review the charts and the plan and let us know when you are ready to begin.
- ☐ When the participant is ready to begin, tell the Control Room to start Scenario 4.
- ☐ If participant said yes to ATC, time for 1 minutes past FL320.
- ☐ Otherwise, if said no to ATC, stay at FL300 stop when reach FL320.
- ☐ Tell the Control Room to stop Scenario 4.
- ☐ Have participant fill out NASA TLX.

During Scenario:
Where possible, mark observations

Observations	Notes (In the moment)
What page in the FMS did the participant have open?	
Did the participant appear to look at the FMS?	
Did the participant say yes or no to ATC?	
How long did it take for the participant to respond to ATC?	
If yes, did they make it to FL320 in time?	
Did the participant revise their response?	
Did the participant vocalize any justification for their response?	
If the participant said yes, what adjustments did the participant make to the flight controls to execute their plan to make it to FL320?	
Did the participant clearly communicate with the PM?	
Did the participant ask the PM for help? If yes, what kind of help?	

Verbal Protocol
Check off as ask each question.

- ☐ What airspeed, altitude, and heading indications did you monitor [NOTE: evidence of applying integration and estimation may emerge in responses to this question.]:
- ☐ Why?
- ☐ How did you prioritize the airspeed, altitude, and heading indicators you monitored?

- ☐ Which airspeed, altitude, and heading indications did you use to make your decision regarding being able to meet ATC's request [NOTE: evidence of applying estimation, prediction and planning may emerge in responses to this question]:
- ☐ Was there anything else you were looking at?
- ☐ How did you use information obtained from flight deck displays with any information from other resources to make your decision about being able to make ATC's request?
- ☐ What knowledge did you use to help you make your decision?
- ☐ How did you use airspeed, altitude, and heading indications to make your decision regarding being able to make ATC's request?
- ☐ Why did you use these indicators to make your decision?
- ☐ If ATC asked you at FL280, can you to make FL360 in five minutes or less, how would you assess if you could make it?
- ☐ Let's say that when you were handed off to departure, they requested that you pass IZZO at FL220. How would you decide if you could make that constraint?
- ☐ What were (or would have been) the effects on airspeed as a result of saying yes to the request?
- ☐ What were (or would have been) the effects of saying yes to the request on the rest of the flight?
- ☐ How did you (or how would you have) adjust flight controls to make the climb?
- ☐ What would you have done if you stayed at a lower than planned altitude?
- ☐ What was the basis for the callouts you made??

Scenario 5 – Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise

Scenario start: Over the ESTWD waypoint at FL340
Scenario stop: After they have entered the hold at MDLER and have been in the hold for five minutes.

Experimenter

- ☐ Tell the Control Room to load Scenario 5
- ☐ As Scenario 5 loads…
  When we paused, you were in the latter climb, making your way to final altitude of FL340. You made it to FL340 and are in cruise now. We are going to resume the flight in cruise just over ESTWD at FL340. Please review the charts and the plan and let us know when you are ready to begin. Add language…
- ☐ When the participant is ready to begin, tell the Control Room to start Scenario 5.
- ☐ After the participant enters the hold, time for 5 minutes. Then tell the Control Room to stop.
- ☐ Have participant fill out NASA TLX.

During Scenario:

Where possible, mark observations

Observations	Notes (In the moment)
Did the participant see the ACARS message?	
Did the participant utilize the FUEL PRED page? (ALTN Time, Final/Time, Extra Time)	
Did the participant look at the release?	
Did the participant ask for any information from ATC? What information did they ask for?	
Did the participant ask for any information about weather? What information did they ask for?	
Did the participant ask for any information about alternate or nearby airports? What information did they ask for?	

Did the participant ask the PM for help in finding any information?
Did the participant actions indicate utilizing multiple information sources? (e.g., requested weather and went to FUEL PRED page)
Did the participant accept the hold?
Did the participant exhibit any hesitation in accepting the hold?
Did the participant ask for information about weather, the alternate airport, or other nearby airports?
How did the participant respond to information about nearby airports being unavailable?
Did the participant take any action after receiving the ACARS message? What action did they take?
Did the participant ask for information about weather, the alternate airport, and other nearby airports? What information do they request?
Did the participant verbalize a plan for the hold?
Did the participant verbalize to the PM their thoughts (and if they had a plan) regarding the hold?
What information did the participant collect verbally?

Verbal Protocol:
Check off as ask each question.

- ☐ Did you have any challenges collecting the information you needed in order to program the hold in the box?
- ☐ Did you have any challenges collecting the information you needed in order to know if you could hold for as long as you might have needed to?
- ☐ What airspeed, altitude, and heading indications did you monitor once you started to enter the hold? Why did you monitor these?
- ☐ How did you use information obtained from flight deck displays with information from other resources to enter the hold in the box?
- ☐ How did you use information obtained from flight deck displays with information from other resources to decide how long you could hold for?
- ☐ What knowledge did you use to program the hold?
- ☐ How would you go about exiting the hold?
- ☐ Did you identify how long you could hold for?
- ☐ How long can you hold for?
- ☐ How did you figure that out?
- ☐ How was weather a consideration?
- ☐ Would you have held for the whole 55 minutes? Why or why not?
- ☐ When would you have considered going to the alternate? Why?
- ☐ Did you thinking about how this might affect your descent?
- ☐ Did you have a plan for how long you would hold for? If yes, what was the plan and why did you have this plan. If no, why not.
- ☐ What was the basis for the callouts you made?

Scenario 6 Energy Management during RNAV Arrival Descent to Los Angeles (KLAX) & Scenario Navigation Source Transition during Arrival-to-Approach Operations

Scenario start: Over the MNROE waypoint
Scenario stop: Landed on RWY 7R.

Experimenter

- ☐ Tell the Control Room to load Scenario 6
- ☐ As Scenario 6 loads…

When we paused, you were holding at MDLER at cruise altitude, FL340. You held for a short time, but the weather is beginning to clear a little, so you were cleared to proceed to KLAX via the BRUEN2 arrival. We are resuming the flight, and you are still at cruise heading towards your top of descent. The flight will resume over the MNROE waypoint at FL340. Please review the charts. If you need to conduct (or finish) your approach briefing, please do so, and let us know when you are ready to begin.

- ☐ When the participant is ready to begin, tell the Control Room to start Scenario 6.
- ☐ After the participant lands at KLAX, tell Control Room to stop.
- ☐ Have participant fill out NASA TLX.

During Scenario:

Where possible, mark observations

Observations	Notes (In the moment)
Did the participant use the F-PLN page in the FMS?	
Did the participant use the DESC (VDEV) when they were in NAV mode or HDG mode to see vertical deviation?	
Did the participant have CSTR enabled?	
Did the participant put speed brakes on before or after “More Drag”?	
Did the participant deploy speed brakes prior to the “More Drag” notification?	
When/where did the participant put speed brakes back down?	
What modes does the participant utilize during the descent?	
What modes did the participant utilize to manage flightpath on the arrival?	
Did the participant utilize the APPR page?	
When did the participant arm the approach?	
When did the participant disengage autoflight?	
Did the participant have their hand up to the MCP in anticipation?	
Did the participant exhibit any other behaviors that indicate “triggers” to help remember to execute certain actions?	
Did the participant clearly communicate with the PM?	
Did the participant ask the PM for help? If yes, what kind of help?	

Verbal Protocol:

Check off as ask each question.

- ☐ What airspeed, altitude, and heading indications did you monitor during the arrival?
- ☐ How did you prioritize the airspeed, altitude, and heading indicators you monitored during the arrival?
- ☐ What did you look at to monitor your vertical flightpath?
- ☐ Did you see a “More Drag” message during the arrival?
- ☐ Was there anything else you were looking at during the arrival? Why or why not?
- ☐ Were you looking at anything on the FMS during the arrival? Why? What does it mean?
- ☐ Did you use the EFB during the arrival?
- ☐ How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath and energy state during the arrival?

- ☐ You mentioned using [airspeed, altitude, heading indications] to monitor your descent. Can you elaborate on how you used these [indications]? [brackets reference specifically referring to how they answered "Collection" question]
- ☐ You put speed brakes on [reference when they enabled speed brakes]. Why did you put the speed brakes on at that point in time?
- ☐ Did wind appear to affect your descent at all?
- ☐ Did the arrival go as you expected it go when you briefed it? Why or why not?
- ☐ Did you anticipate you would need speed brakes when you received the speed reduction from ATC? Why or why not?
- ☐ How did deploying speed brakes affect your flightpath?
- ☐ You used [which mode they used, NAV, HDG, etc.]. Can you talk about why you used this mode?
- ☐ When you were able to resume published speeds, you resumed speeds by [reference what they do]. Can you talk about why you resumed speeds this way?
- ☐ How did callouts about FMAs affect your flightpath management in the arrival?
- ☐ What was the basis for the callouts that you made in the arrival?
- ☐ What airspeed, altitude, and heading indications did you monitor during the approach? Landing?
- ☐ How did you prioritize the airspeed, altitude, and heading indicators you monitored during the approach? Landing?
- ☐ Was there anything else you were looking at during the approach? Landing? Why or why not?
- ☐ Were you looking at anything on the FMS during the arrival? Why? What does it mean?
- ☐ Did you use the EFB during the approach? Landing?
- ☐ How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath and energy state during the approach? Landing?
- ☐ You mentioned using [airspeed, altitude, heading indications] to monitor your approach. Can you elaborate on how you used these [indications]? [brackets reference specifically referring to how they answered "Collection" question]
- ☐ Did you consider how weather might impact your approach and landing?
- ☐ How did you verify that the performance of the aircraft was what you were expecting to get in regard to:
    - vertical flightpath
    - lateral flightpath
    - speed
- ☐ Were you anticipating any changes to the approach that could affect the flightpath? Why or why not?
- ☐ What information did you use to make decisions to:
    - Disengaging autoflight systems
    - Continuing approach
- ☐ How did callouts about FMAs affect your flightpath management in the approach?
- ☐ What was the basis for the callouts that you made in the approach?
- ☐ Did you have any memory aids, mnemonics, or other actions that you take to help you with completing tasks?

<u>Debrief</u>

Experimenter

- ☐ Offer break.
- ☐ Then proceed to briefing room.

    Thank you so much for your time today! We just have a few more questions for you and a questionnaire for you to fill out.
- ☐ Ask questions and then have fill out questionnaire.

Questions

- ☐ In general, how did you feel about the flight today?
- ☐ What is flightpath management to you?

- ☐ Did this flight end up the way you thought it would from a flightpath management perspective?
- ☐ Which one of the scenarios was the most challenging for you in terms of managing your flightpath?
- ☐ Was there any information that you feel was missing across the scenarios that would have helped you manage your flightpath?
- ☐ How do you think having ATC chatter would have affected your mental model of your flightpath?
- ☐ What callouts from your PM would have helped with flightpath management?
- ☐ For knowledge that you used to make decisions, like responding to ATC's request about making it to FL320 in two minutes or less, how/when did you obtain that knowledge?

APPENDIX C – FLIGHT RELEASE

A320 Release

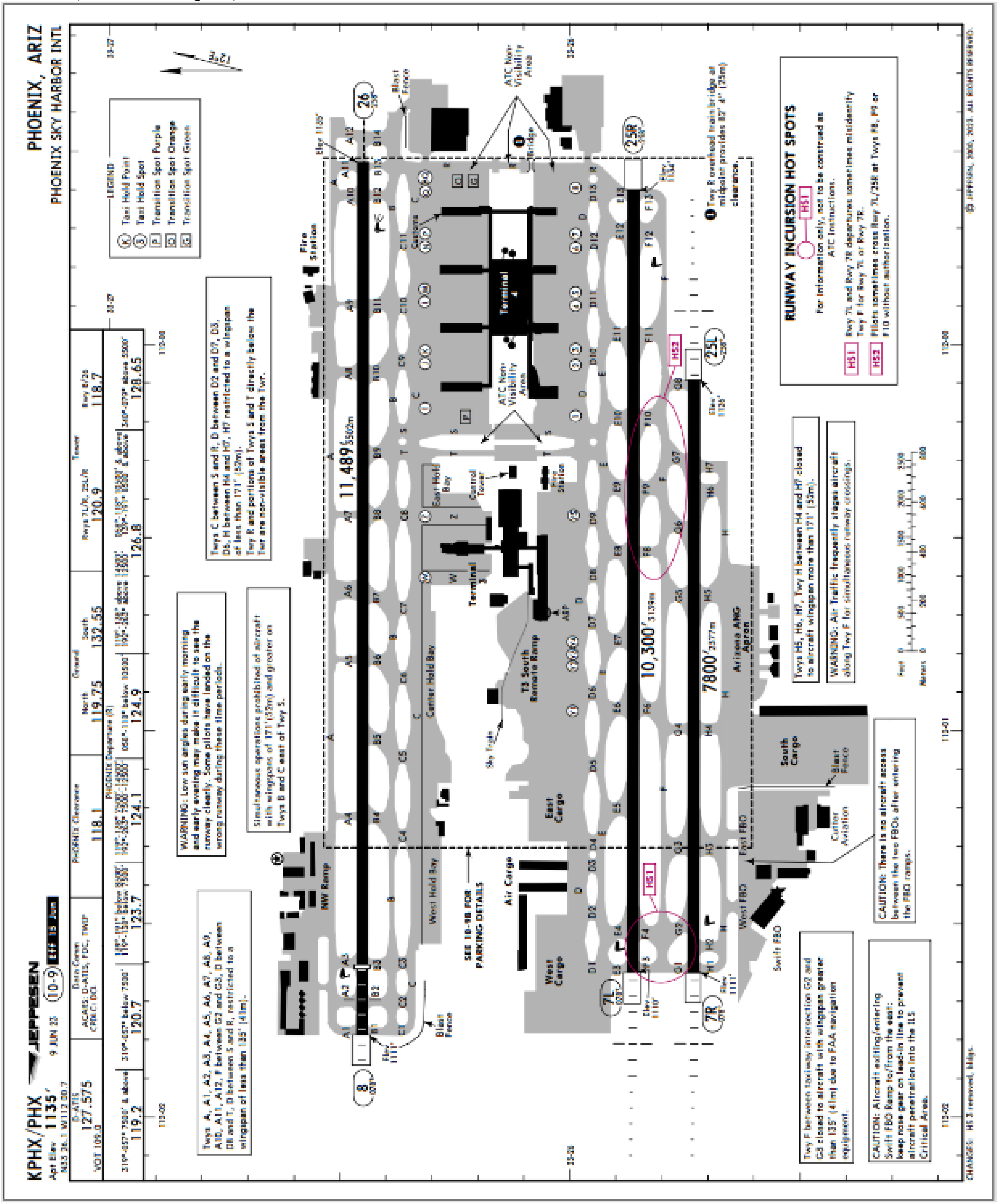
2.ReleasePerfData_A320.pdf

B737 Release

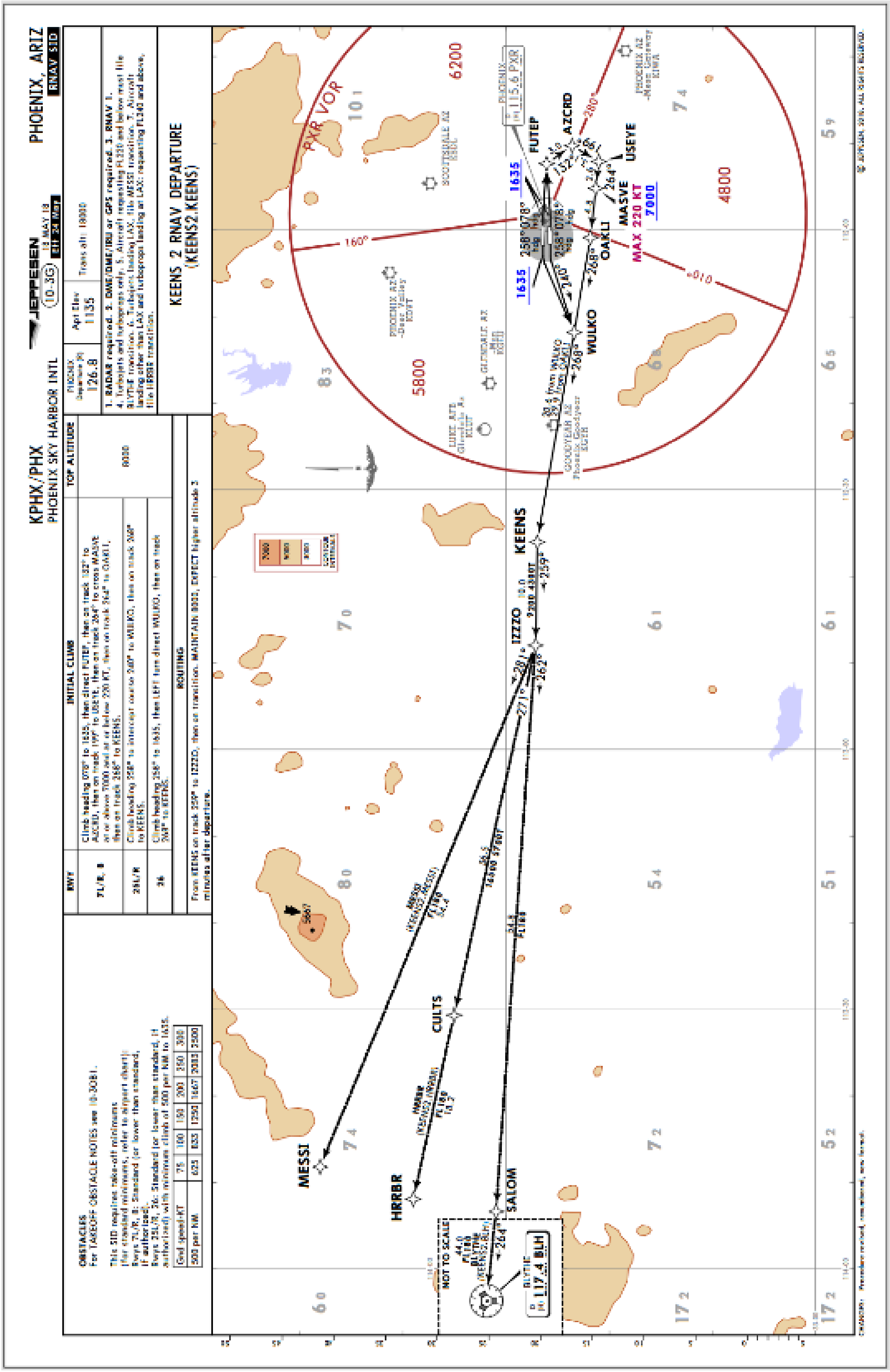
2.ReleasePerfData_B737.pdf

APPENDIX D – AERONAUTICAL PUBLICATIONS

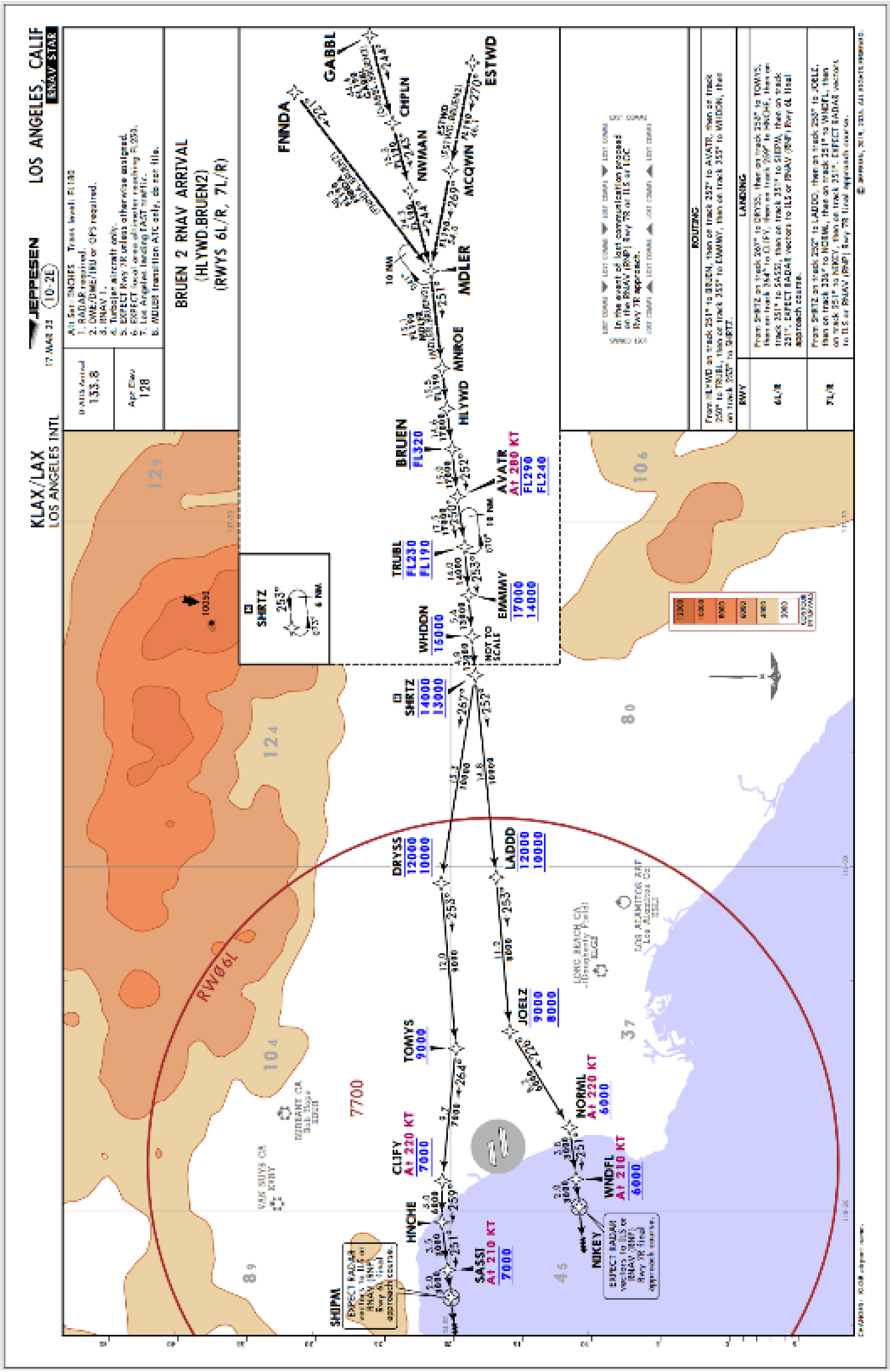
KPHX (Phoenix Airport)



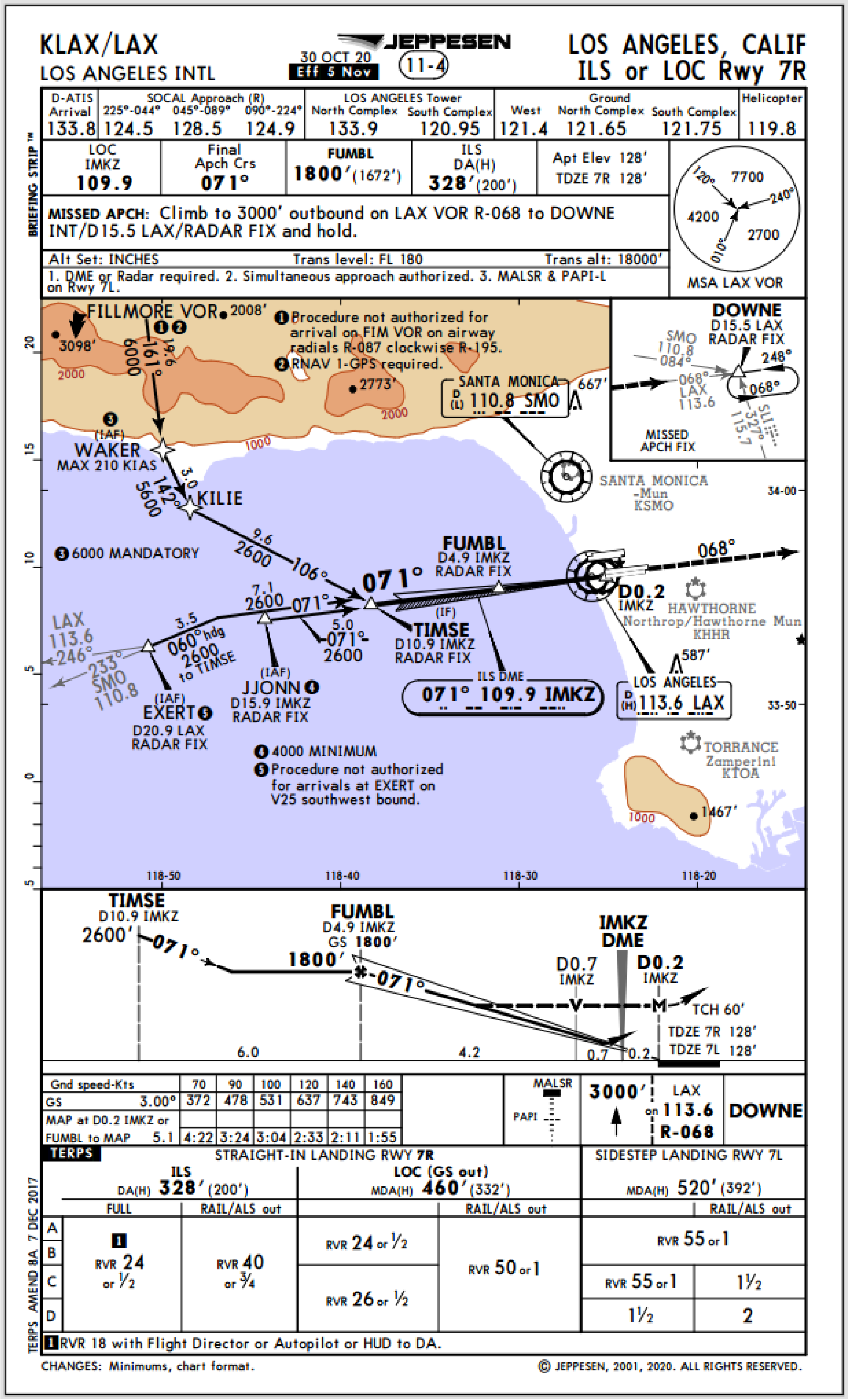
RNAV Departure – KEENS2



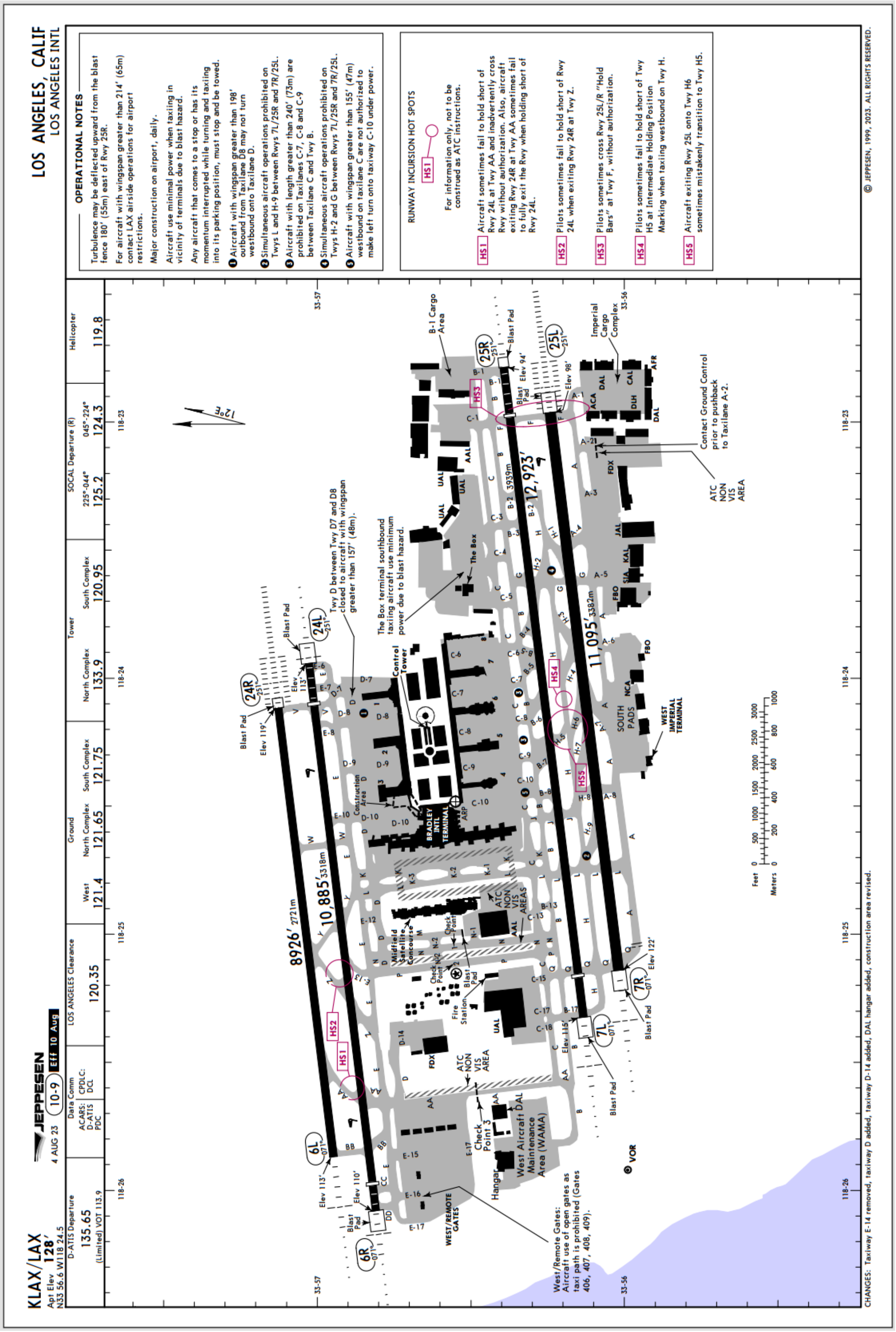
RNAV Arrival – BRUEN2



ILS Approach Runway 7R



Los Angeles Airport (KLAX)



APPENDIX E – ATC

Scenario 1: No ATC

Scenario 2: Clearance provided by experimenter.

Scenario 3:

[Holding short of runway 7L]
Pilot: requests takeoff clearance…
ATC: MAC689, winds 030 at 10 knots, RNAV to FUTEP, clear for takeoff Rwy 7L

[2500 feet MSL after takeoff, switch to departure]
ATC: MAC689 contact departure 126.8.

[when pilot checks in with departure]
ATC: MAC689, radar contact

[only when pilot requests higher]
ATC: MAC689, climb and maintain FL220.

Scenario 4:

[20,000 feet]
ATC: MAC689 contact Albuquerque center 135.15.
Pilot: Checks in
ATC: MAC689 Albuquerque center roger climb and maintain flight level 320.

[at FL280]
ATC: MAC689 Albuquerque center, climb and maintain flight level 340; I need you through flight level 320 in **<u>two</u>** minutes or less for traffic, let me know if you can't make it.

- If the pilot says they are unable to make it– level them at FL300 or closest altitude for 1 min, then clear them to FL340.
- If the pilot asks if they can slow down to make it, allow them to do that.
- If the pilot requests something different (e.g., for a different altitude or more time to make request, such as through FL320 in 3 or more minutes) – deny request and level them at FL300 or closest altitude for 1 min.

Scenario 5:

[crossing point ESTWD]
ATC: MAC689 contact Los Angeles center on 127.52.

[30 miles to MCQWN]
ACARS message is sent.

[10 miles after MCQWIN, 25 miles to MDLER]
ATC: MAC689, LA Center, I have holding instructions, advise when ready to copy.
Pilot: MAC689, ready to copy
ATC: MAC689, hold as published at MDLER, FL320; expect further clearance @time [add 55 minutes to the time, convert to ZULU]

- If pilot asks for NON-published HOLD, say NO.
- Approve pilot requests to slow down early or adjust the holding pattern (leg distance, inbound radial, etc.)
- If the pilot requests clearance to divert, respond with "standby for coordination."
- If the pilot cannot enter the hold, then give them vectors…
    - "Fly heading 041, expect vectors until further clearance in 50 minutes."

Scenario 6 and 7:

Do not allow the aircraft to descend early. If they ask, tell them unable due to crossing traffic underneath.

[at TOD]

ATC: MAC689 descend via the BRUEN2 for Rwy 7R, altimeter 30.00.

- TOD occurs after HLYWD.
- If the pilot asks for clearance for the arrival earlier than TOD, state: "MAC 689, expect clearance in X miles" and estimate based on location of HLYWD.

[crossing point BRUEN]

ATC: MAC689 Los Angeles Center contact SoCal approach on 124.0
Pilot: Checks in
ATC: MAC689, SoCal approach, expect ILS runway 7R. After AVATR, maintain 250 knots until JOELZ. Resume published speeds at NORML.

- If pilot says they cannot make the altitudes, tell them "MAC 689, SoCal approach, maintain 250 and do your best on the altitudes."

[crossing point NIKEY]

ATC: MAC689 descend and maintain 3000, heading 250.

[~7.5NM after NIKEY]

ATC: MAC689 turn right heading 340, slow to 180 knots.

[~2.5NM from final approach course]

ATC: MAC689 turn right heading 040 maintain 2000 until established on the localizer cleared ILS RW 7R.

[2 mi to FUMBL]

ATC: MAC689 contact Los Angeles tower on 120.95.
Pilot: Checks in
ATC: MAC689 Los Angeles tower, winds 360 at 10, cleared to land RW 7R.
ATC: MAC689, left when able, contact ground 121.75.

If pilot asks for alternate climb-out procedures…
ATC: "fly runway heading, climb and maintain 3000 ft, expect vectors"

APPENDIX F – CHECKLISTS

A320 Checklist

Preflight

Interior & exterior inspection	complete	C
Recorder	ON	C
Passenger signs	ON & AUTO	C
Emergency lights	ARM	C
Altimeters	__, xckd	C&F
Flight & nav instruments	ckd	C&F
ECAM status	ckd	C
Parking brake	set	C
Radar	OFF	C
*Radios & transponder	set	C
Windows	closed & locked	C&F
Oxygen mask	ckd	All
Flight attendant briefing	complete	C
*Departure briefing	complete	C
Logbook & QRHs	onboard	C
Fuel required	____ onboard___	C&F

Pushback

Doors	closed	F
Flight deck door	closed & locked	F
Transponder	AUTO	F

After Start

Engine anti-ice	as reqd	C
ECAM status	ckd	F
Climb derate	set	F

Taxi

*Flaps	___,___,___	C&F
*Takeoff speeds	___,___,___	C&F
*Thrust	TOGA / FLEX ___	C&F
*Trim	___,0	C&F
Flight Controls	ckd	C&F

Before Takeoff

*Runway position	___,___	C&F
*Takeoff memo	all green	C&F
Brake temps	ckd	F
*Navigation briefing	complete	C
TCAS	TA/RA	F
Flight attendants	notified & ack	F

* Re-accomplish items for rwy / performance change

After Takeoff

Flaps	up	
Landing gear	up	
APU	off	

Climb

Altimeters	STD, xckd	C&F

Descent

Altimeters	___, xckd	C&F
*Minimums	___,___	C&F
*Approach briefing	complete	PF
Autobrakes	as reqd	PM
Seat belts sign	ON	PM

Approach

* Flight & nav instruments	verified	C&F
Cabin notifications	complete	C
*FMS flight phase	APPR/DES	PM
Altimeters	___, xckd	C&F

Landing

Landing gear	down	C&F
Flaps	___,___	C&F
Spoilers	ARMED	PM

After Landing

Flaps	up	
Spoilers	retracted	
Radar	OFF	

* Re-accomplish items for rwy / performance change

Departure Briefing

Threats (PM then PF):

Relevant threats/concerns refer to:

- Potential Threats
- Mandatory Off Time (MOT)

Plan (PF):

- Taxi:
  - Planned route (including hot spots/rwy crossings)
  - Departure runway
- Takeoff:
  - Performance data
  - Rejected takeoff considerations
- Departure:
  - Planned departure (initial heading/altitude/fix)
  - Emergency (EO SID, EO accel/alt, alternate, return)

Approach Briefing

Threats (PM then PF):

Relevant threats/concerns refer to:

- Potential Threats

Plan (PF):

- Arrival: arrival, transition and approach name:
  - Top of descent point
  - First published altitude constraint
- Approach: type
  - Day VMC visual approach identify the:
    - Landing runway
    - Backup approach
  - Instrument approach or night VMC visual approach:
    - Airport, approach name
    - Minima
    - Glide path
  - Go-around considerations
- Landing/taxi
  - Runway data (length, surface, condition, expected wind)
  - Landing performance assessment
  - Flaps
  - Autobrakes
  - Expected taxi route

B737 Checklist

Before Start - Originating

Logbook	Aboard
Landing Gear Pins	3 Aboard
Fire Warning and Overheat	Checked
Start Levers	CUTOFF
Stab Trim Cutout Switches	NORMAL
Lights Test	Checked

Before Start

FMC	Programmed
Briefings	Complete
Oxygen Masks and Quantity	Checked
EECs	ON
Navigation Switches	NORMAL
Displays Switches	AUTO and NORMAL
Fuel	_____ Cleared with ______ Center pumps ON/OFF
Passenger Signs	ON
Window Heat	ON
Hydraulic Pumps	A's OFF, B's ON
Pressurization	Set, AUTO
Flight Instruments	______, ______, SET
Auto Brake	RTO
Takeoff Warning Horn	Checked
Parking Brake	Set
Transponder	TA/RA
Aileron and Rudder Trim	Centered

Before Push

Zero Fuel Weight	______, Set
Gross Weight	______, Crosschecked
PWB Remarks	Reviewed
N_1s	______/______, Reduced Set Or _______, MAX set
Runway	______/______, Set
Flaps	PWB _______, CDU ______
V Speeds	______, ______, ______, Set
Stab Trim	______, Set
Min Cleanup Altitude	______,Set Or ______, ______, Set
Flight Deck Door	Lights Out

Before Taxi

Electrical	Generators ON
Probe Heat	ON
Anti-Ice	As Required
Flight Controls.	Free
Flight Deck Windows.	Closed and Locked
Flaps	CDU ____, Indicates___, Green Light

Before Takeoff

Min Takeoff Fuel	Verified
Departure Plan	Not Reqd/Complete
Attendant Notification	Complete
Electrical	Generators ON
Anti-Ice	As required
Packs	As required
Bleeds	As required
Start Switches	Left, CONT
APU	As required
Flaps	CDU ____, Indicates___, Green Light
Start Levers	IDLE
Recall	Checked

Climb

Pressurization	Checked
Start Switches	As Required
APU	As Required

Descent

Minimums	Set
V_{REF} and V_{TARGET}.	_____,_____,Set
Auto Brake.	As Required
Recall.	Checked

Approach

Altimeters	______,______, Set
Packs.	AUTO
Start Switches	As Required

Before Landing

Speedbrake	ARMED, Green Light
Landing Gear	DN, 3 Green
Flaps.	______, Green Light

Departure Briefing

Threats:

Relevant threats/concerns refer to:

- Potential Threats
- Mandatory Off Time (MOT)

Plan (PF):

- Taxi:
  - Planned route (hot spots/rwy crossings)
  - Departure runway
- Takeoff:
  - Performance data
  - Rejected takeoff considerations.
- Departure:
  - Planned departure (initial heading/altitude/fix)
  - Emergency (EO SID, EO accel/alt, alternate…)

Approach Briefing

Threats:

Relevant threats/concerns refer to:

- Potential Threats

Plan (PF):

Arrival: arrival, transition and approach name:

- Top of descent point
- First published altitude constraint

Approach: type

- Day VMC visual approach identify the:
  - Landing runway
  - Backup approach
- Instrument approach or night VMC visual approach:
  - Airport, approach name
  - Minima
  - Glide path
- Go-around considerations

Landing/taxi

- Runway data (length, surface, condition, wind)
- Landing performance assessment
- Flaps
- Autobrakes
- Expected taxi route

APPENDIX G – DEMOGRAPHICS QUESTIONNAIRE

Participant ID________ **Date ___________**

Total Flight Hours: _____________

List all Type Ratings:

List all 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 types)

At your operator, which aircraft are you qualified and current to fly? (Please list specific types)

At your operator, which aircraft have you flown most recently? (Please list specific types)

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 pilot: 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.

APPENDIX H – RAW TASK LOAD INDEX (RTLX)

Participant ID________ **Date ___________**

Scenario ________

How mentally demanding were the tasks?

Very Low 1 2 3 4 5 6 7 Very High

How physically demanding were the tasks?

Very Low 1 2 3 4 5 6 7 Very High

How hurried or rushed was the pace of the tasks?

Very Low 1 2 3 4 5 6 7 Very High

How successful were you in accomplishing what you were asked to do?

Perfect 1 2 3 4 5 6 7 Failure

How hard did you have to work to accomplish your level of performance?

Very Low 1 2 3 4 5 6 7 Very High

How insecure, discouraged, irritated, stressed, and annoyed were you?

Very Low 1 2 3 4 5 6 7 Very High

APPENDIX J – BASIS FOR CODING

Scenario #0: Flight Plan Review and Assessment

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Review printed information about aircraft weight, fuel, the filed flight plan, weather, procedures, notice to air missions (NOTAMs), MEL. Review aeronautical publications in EFB, including departure, arrival, approach plate, airport diagram.	• Observe physical actions to collect information. ○ Did the participant look at every page of the provided documentation? ○ Did the participant look at aeronautical publications? ○ How long did the participant spend reviewing the release and aeronautical publications? ○ Did the participant use electronic or paper for aeronautical publications? ○ Did the participant make any requests for information? • Observe verbal indicators from protocol of collecting information: ○ Was the participant able to identify all the information they wanted to collect and then figure out a way to collect it / know where to collect it (e.g., did they have any challenges)? ○ Did information systems have any impact on information collection (digital media vs. paper)?	• Did you have any challenges collecting information from this flight release? • Do you prefer paper or electronic information when reviewing a flight release and a flight plan? • Does the type of media impact how you collect and annotate information? • Is there any additional information you would request?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Compare and cross reference information about filed flight plan, weather, MEL, weight, NOTAMs, and aeronautical publications in EFB. Combine information with local knowledge to create an initial understanding of the flight operation before it occurs.	• Observe physical actions to integrate information: ○ Do they go back and forth between release and aeronautical publications? • Observe verbal indicators from protocol of integrating information: ○ Did the participant combine information about aircraft performance with knowledge of aircraft? ○ Did the participant integrate information about NOTAM with other knowledge and information about the flight? ○ Did the participant combine local knowledge with information from the release?	• What knowledge about aircraft performance did you leverage when reviewing the flight release? • What NOTAMs are applicable to the route of flight, and why? • What operational experience do you have at Phoenix? Based on this experience were their other things you considered? • What operational experience do you have at Los Angeles? Based on this experience were their other things you considered?
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Approximately calculate to evaluate whether fuel, loading, fuel burn, and schedule will align appropriately based on environment and flight plan. Judge effects of winds and turbulence on altitude changes along flight plan for strategic planning.	• Observe physical actions indicative of estimation: ○ Do they ask for any additional information regarding fuel, weight, or weather? ○ Do they request or mention more fuel? • Observe verbal indicators from protocol of estimation: ○ Did the participant perform any heuristics or rough math to assess that the fuel, weight, performance, etc. makes sense with the flight plan and weather? What kinds of estimations or heuristics do they perform? ○ Did the participant collect the information prior to be asked about it?	• How did you determine if the information the dispatcher provided in this flight release is an accurate reflection of what is needed to complete the flight? ○ Fuel ○ Weight ○ Performance ○ Weather
Prediction *Envision future events based on estimation of incomplete information in the present*	Determine if and how collected information might have an impact on the flight (e.g., planned/actual fuel reserves, weight, NOTAMs, MEL items, weather). Utilize estimations to think ahead about the flight and build on understanding of the plan for the flight before it occurs.	• Observe physical actions indicative of prediction: ○ Do they ask for any additional information regarding fuel, weight, or weather? ○ Do they request or mention more fuel? • Observe verbal indicators from protocol of prediction? ○ Can the participant verbalize what information they need to in order to develop a mental model for the flight?	• What is the minimum information you need to review in order to develop a mental model of the flight before it occurs?

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol

Planning
Formulate and identify a strategy, approach, and set of tasks or actions
	Take actions based on estimation and prediction to ensure strategic plan for the flight.	• Observe physical actions indicative of planning:
		  ○ Did they mark up the aeronautical publications (e.g., marking taxi route)?
		  ○ Did the participant make any notes?
		• Observe verbal indicators from protocol of planning:
		  ○ Did the participant make notes before being asked about making notes?
		  ○ What notes did the participant make?
		  ○ Why do they say they make the notes they make?
			• What information from the flight release did you prioritize from most important to least important, and why?
			• Are there any NOTAMs that might impact this flight?
			• Is there information missing from this flight release? If yes, what information is needed and from what source?
			• Did you make any notes as you reviewed the release? If yes, what notes did you make?
			• Did you make any notes as you reviewed the aeronautical publications? If yes, what notes did you make and why?
			• If participant did not make notes and then goes back to make notes, ask them about why they did not initially make any notes.

Communication
Applying intelligent reasoning to identify when and how to communicate with ATC and co-pilot
	Ask PM or dispatch clarifications about the plan. Discuss / verbalize thoughts about plan (NOT prompted by experimenter) to communicate their understanding of the flight to the crew.	• Observe physical indicators of communication:
		  ○ Did they talk about the release out loud?
		  ○ Did they make any requests of additional information or changes to the release?
		• Observe verbal indicators from protocol of communication:
		  ○ Did the participant know of / recall additional information they would expect?
		  ○ What information would the participant think is important to communicate and would use to ensure similar mental model?
			• Is there any information you would provide or receive from dispatch prior to a pre-briefing?
			• What information would you emphasize during your pre-brief with another crewmember?

NOTE: There are actions and questions that are related. For example, "Observation: did the pilot take notes" and "Verbal Protocol: "did you make any notes as you reviewed the release? If yes, what notes did you make." Analysis will consider the relationship between observations and statements.

EXAMPLE

Planning: *Formulate and identify a strategy, approach, and set of tasks or actions.*

Example Data	Potential Observation / Response (P1)	Potential Observation / Response (P2)	Potential Observation / Response (P3)
Observation: Did the Participant make any notes?	Participant did NOT make any notes	Participant did NOT make notes	Participant DID make notes
Verbal Protocol: Did you make any notes as you reviewed the release? If yes, what notes did you make and why?	I did not make any notes and yeah actually… I would normally… probably write our call sign, the fuel, make a note of the runway, and about closures… were there any closures? [looks at release], oh no, nothing that will affect us. [why] to help me when I get to the aircraft, kind of plan ahead if there is something there.	I did not make any notes; I wouldn't normally make notes. [why not] because I don't need them, I can remember everything. I've never had problems remembering what I need to know.	I made a note about the weather, about the fuel, and I wrote down our runway. I saw there weren't any closures so we're good there. And I made a note on the weather – it's a little warm. Oh, and I wrote down our call sign. [why] I write it down to help me remember and to start to help me know/think about the pertinent stuff, which might matter. Like it's a little warm, not really hot, but if it was hot, I'd want to be sure to be thinking about that.
Researcher Codes for Plan:	Participant actual notes: none Participant verbal response on notes: yes - call sign - fuel - runway - closures Discrepancy between action and words: yes	Participant actual notes: none Participant verbal response on notes: none Discrepancy between action and words: yes [occurred later when participant did not remember]	Participant actual notes: yes: call sign, fuel, runway, closures, weather Participant verbal response on notes: yes: call sign, fuel, runway, closures, weather Discrepancy between action and words: yes
For planning, we are evaluating note taking (among other activity) because it may indicate that they are "planning ahead" with information that they may need during the flight to effectively manage the flight and flightpath. Which notes they take can indicate the extent to which they are planning. Not making any notes may indicate that they (1) may not be treating the flight as seriously as they would on-the-line, (2) potentially that there is some degradation with regard to how they would have planned had they not had time away, or (3) they do not use notes to facilitate planning.			

Scenario #1: Pre-Flight Preparations and Flight Deck Setup

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Review pre-departure clearance that is pre-loaded in the FMS. Gather information about the route, altitudes, constraints, speeds, weight, fuel, and environment.	• Observe physical actions to collect information: ○ Did the participant look at INIT, F-PLN, SEC F-PLAN, Radio NAV, FUEL PRED, PERF TAKEOFF? ○ Did participant enable CSTR? ○ Did participant enable TERR? ○ Did participant enter PLAN mode in ND and scroll through F-PLN while checking ND? • Observe verbal indicators from protocol of collecting information: ○ Was the participant able to identify all the information they wanted to collect and then figure out a way to collect it / know where to collect it (e.g., did they have any challenges)? ○ Did information systems have any impact on information collection (digital media vs. paper)?	• Did you have any challenges collecting information from the clearance pre-loaded in the FMS? If yes, can you describe these challenges? • Did you have any issues finding the information needed to brief the taxi route, departure procedure, route of flight, aircraft performance or other operational considerations? If yes, can you describe these issues? • Did you have any issues recalling the information needed to brief this information? If yes, can you describe these issues? • If the participant indicated potential difficulties recalling information (e.g., hesitated, asked PM, made filler noises indicating recall issues) but did not answer yes to the last question, ask them about what appeared to be difficult.
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine sources of visual information to check the FMS for route discontinuities, data entry errors, and potential anomalies.	• Observe physical actions indicating information integration: ○ Did the participant reference the release while checking the loaded plan? ○ Did the participant check aeronautical charts while checking the loaded plan? ○ Do they utilize PLAN mode in ND? ○ Did the participant dial in 8000'? • Observe verbal indicators from protocol of integrating information: ○ What information did the participant say they combined?	• What information from the flight release and pre-loaded clearance did you compare? • Are there any other resources you use to obtain and integrate information? • How did you check the FMS to verify the computed targets appropriately align with crossing restrictions? • If the participant says yes here but they did not look at the FMS, inquire further as to how/what they checked. • Did you identify discrepancies between information sources? If yes, how did you recognize them? • Did you perform any data entry? If yes, what did you enter and why?
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Apply heuristics and estimations to develop expectations for the flight and flightpath from knowledge, mental schema, and flight information in the FMS, release, other flight documents, and aeronautical publications.	• Observe physical actions indicating estimation: ○ Did the participant mention fuel, weight, performance, terrain or weather within the context of potential effects on the flight? • Observe verbal indicators from protocol of estimation: ○ Did participant say they made estimations about whether the runway was appropriate, reasonable V1, VR, V2, FLEX/TOGA, final fuel load?	• How did you verify if aircraft performance calculations are correct and appropriate for the situation?
Prediction *Envision future events based on estimation of incomplete information in the present*	Using expectations and estimations, forecast altitude, speeds, fuel, and overall plan. Evaluate if pass reasonableness checks for meeting constraints, fuel loading, weather expectations.	• Observe physical actions indicative of prediction: ○ Do they ask for any additional information regarding fuel, weight, or weather? ○ Do they request or mention more fuel? ○ Did the participant mention fuel, weight, performance, terrain or weather within the context of potential effects on the flight? • Observe verbal indicators from protocol of performing predictions: ○ Did the participant say they did any mental forecasting and what information sources helped them to do that?	• Can you list in the order of importance information that helped you develop a mental model of the flight before it occurs?

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol

Planning
Formulate and identify a strategy, approach, and set of tasks or actions
	Develop plan for adjusting or updating flightpath management targets based on estimations and predictions.	• Observe physical action indicating planning:
		  ○ Do they utilize PLAN mode in ND?
		  ○ Do they have CSTR enabled?
		  ○ Do they have TERR enabled?
		  ○ Do they brief terrain?
		  ○ Do they brief weather?
		  ○ Do they mention fuel, weight, or weather?
		  ○ Do they request or mention more/or less fuel?
		  ○ Do they talk about when they are going to enable autoflight?
		• Observe verbal indicators from protocol of planning:
		  ○ What were participant reasons participant verbalizes for briefing or not briefing weather? Terrain?
			• You [did/did not] brief terrain. How [was/was not] terrain a factor?
			• You [did/did not] brief weather. How [was/was not] weather a factor?
			• You [did/did not] brief when you were going to enable autopilot. Can you tell me why you [did/did not] brief it and why?
			• Utilized ND: I noticed you used/did not use the ND to review the flight. Can you tell me why?
			• CSTR Enabled: I noticed you had/did not have CSTR enabled. Can you tell me why?
			• Did you enter a secondary flight plan? Why or why not?

Communication
Applying intelligent reasoning to identify when and how to communicate with ATC and co-pilot
	Brief the plan using mental model as foundation for communicating expectations. Referencing may include potentially putting the Nav display in various modes and/or reviewing various pages in the FMS.	• Observe physical actions indicating communication:
		  ○ Did the participant follow briefing checklist or do their own version?
		  ○ Did the participant ask the PM for their perspective on threats?
		  ○ Did the participant discuss expectations for the takeoff and departure beyond basic details?
		  ○ Did the participant discuss expectations for the flight overall?
		• Observe verbal indicators from protocol of communication:
		  ○ Ask participant about their communication choices, what information they might expect from communications, or would they utilize communication to obtain, and how would they exercise communication to ensure plan/aligned with PM.
			• I noticed that you [used/did not use] the briefing checklist. Can you tell me why?
			  ○ You did not brief taxi. Can you talk about why?
			  ○ You did not brief the performance data. Can you talk about why?
			  ○ You did not brief rejected takeoff considerations. Can you talk about why?
			  ○ You did not brief the planned departure. Can you talk about why?
			• You did not brief emergency procedures. Can you talk about why?
			• I noticed that you [did/did not] ask your PM about threats. Can you tell me why?
			• What other information would you expect to receive that you have not?

Scenario #2: Area Navigation (RNAV) Departure from Phoenix (KPHX)

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Gather data from the PFD, ND, FMS, and EFB to look at the current lateral flightpath (waypoints, heading, constraints) and current vertical path (altitude, vertical speed, airspeed, thrust, and current FMAs). Look out the window and at the EFB / ND for wind, weather, traffic and insight into aircraft state.	• Observe physical actions to collect information: ○ Did they reference the EFB? What information was displayed on the EFB? ○ Did they the enable TERR and CSTR? ○ What pages did they have showing on the FMS? ○ Did they make a request to ATC for information? • Observe verbal indicators from protocol of collecting information: ○ Do they indicate via the verbal protocol that they are (or are not) using and/or thinking about V1, VR, V2, Green F, Green S, FMAs: FLX MCT/MAN FLX/CLB Thrust; SRS/CLB, SRS/ALT, CLB/ALT; NAV, VSI, path, constraints (EFB/ND), distances, wind speed and direction, speed, altitude? ○ Are they collecting information effectively? (e.g., how are they prioritizing how they collect) ○ Did the data they collect align with what they briefed?	• What airspeed, altitude, and heading indications did you monitor during [NOTE: evidence of applying integration and estimation may emerge in responses to this question.]: ○ takeoff roll ○ initial climb ○ established climb. ○ level-off (if they did not request higher) Why or why not? ○ If they do not say what indications but point or gesture, make sure to ask follow-up. ○ Ask detailed follow-up about as needed to clarify. • Which airspeed, altitude, and heading indications do you prioritize during [NOTE: evidence of applying prediction and planning may emerge in responses to this question]: ○ initial climb ○ established climb. ○ level-off (if they did not request higher) Why or why not? ○ If they do not say what indications but point or gesture, make sure to ask follow-up. ○ Ask detailed follow-up about as needed to clarify. • Was there anything else you were looking at? [NOTE: Goal of this question is to elicit if they were leveraging CSTR on ND, TERR on ND, FMS – F-PLN, FMS – PERF, publications on EFB] ○ Why or why not? • What information did you collect from the FMS before/after takeoff, and why? What triggered you to reference the FMS? • How did you use the FMS to verify position after takeoff? • What information did you collect from the EFB before/after takeoff, and why? What triggered you to reference the EFB? • How did you monitor constraints during climb? Did you reference other FMS pages?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine collected information from PFD, ND, FMS, and EFB as well as environment. Collected information should support pilot understanding of where the aircraft should be in space and what the energy state should be, where the aircraft is actually going and its actual energy trend, and where the aircraft should be going and what it's energy trend should be.	• Observe physical actions indicating integrating integration: ○ If they made a request to ATC for more information, what kind of request did they make? [a query to ATC for continuing departure climb suggests information integration – unpack with verbal protocol] • Observe verbal indicators from protocol of integrating information: ○ Do they indicate that they were putting information together to understand their flightpath, manage takeoff, and manage climb?	• How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath during: ○ takeoff roll ○ initial climb ○ established climb. ○ level-off (if they did not request higher) • How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your energy state during: ○ takeoff roll ○ initial climb ○ established climb. ○ level-off (if they did not request higher)
Estimation *Form judgements of when airplane might get to next fix, traffic*	Perform rough calculations based on integrated information to judge aircraft's intended lateral and vertical trajectory in space and intended energy trend and how it incorporates constraints	• Observe physical actions indicating estimation: ○ When did they participant make their request to ATC? [a query to ATC for continuing departure climb suggests estimated impact of continuing without clearance – unpack with verbal protocol]	• How you estimate the effects of hot weather or high-altitude on your performance? Why or why not? [if yes, how]

positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.		○ When did participant complete aircraft configuration changes? [unpack if estimation involved with verbal protocol; later might imply estimation; might imply degradation of not just cognitive skills] ○ When did participant engage autoflight systems? [unpack with verbal protocol] • Observe verbal indicators from protocol of estimating: ○ Did the participant indicate any kind of mental reasoning (e.g., estimation) regarding effects of hot weather, or any other considerations, on performance during takeoff, climb? ○ When the participant was observing indicators, were they actually thinking or performing any form of estimation of flightpath based on indicators? Or were they passively consuming? ○ Did the participant estimate or consider effects of flex temp on performance in takeoff, climb?	• You mentioned using [airspeed, altitude, heading indications] to monitor your climb performance. Can you elaborate on how you used these [indications]? [brackets reference specifically referring to how they answered "Collection" question] • How did you consider the flex temp at takeoff? • Why did you choose to engage autopilot when you did? • Why did you choose to complete aircraft configuration changes when you did? • If the participant engaged autopilot at a different time than they briefed, inquire about why. • How did you verify if final aircraft performance calculations are correct and appropriate for the situation?
Prediction *Envision future events based on estimation of incomplete information in the present*	Make projections of when aircraft should get to next fix based on what the trend and trajectory of the aircraft should be, project meeting of constraints based on intended trajectory, project traffic positions of other aircraft, effects of traffic on intended flightpath, and effects of weather. Projections should include modeling effects on pitch, attitude, and speed as the aircraft should execute maneuvers	• Observe physical indicators of prediction: ○ Observe when/where pilot engages autopilot. ○ Observe when/where completes aircraft configuration changes. ○ Observe when/if participant queries ATC about continuing the departure climb? • Observe verbal indicators from protocol of prediction: ○ Did the participant predict a need to ask ATC for higher altitude? ○ Did the participant predict or think ahead about the flightpath?	• How did you use the FMS to predict a future flightpath or location after takeoff? • How far in advance do predict a flightpath? Is it based on distance? Is it based on time? • Did you use the navigation display to enhance position awareness? How did you use this information during the departure climb? • You [did/did not] ask ATC about continuing departure climb. [If did] What made you realize you should ask ATC about continuing the departure climb? [If did not] Can you talk about why you did not? [if not mentioned in answer, ask follow-up about operational experience in Phoenix and if this played a role in their decision]. • How did you verify that the performance of the aircraft was what you were expecting to get in regard to: ○ vertical flightpath ○ lateral flightpath ○ speed during the departure. • Were you anticipating any changes to the departure that could affect the performance? Why or why not?
Planning *Formulate and identify a strategy, approach, and set of tasks or actions*	Determine and decide on action to adjust the flightpath and energy controls based on comparison of actual vertical position, actual lateral position, and actual energy state to intended and comparison of actual vertical trajectory, actual lateral trajectory, and actual energy trend to intended/expected	• Observe physical indicators of planning: ○ Observe crew callouts related to establishing targets for airspeed, altitude, thrust, and trajectory (tactical planning based on changing situation) • Observe verbal indicators from protocol of planning: ○ How did the participant make decisions about engaging autoflight systems, completing configuration changes, and querying ATC? [was it training, rote action/procedure, conscious thought]	• What information did you use to make decisions to: ○ Engage autoflight systems. ○ Complete aircraft configuration changes ○ Query ATC about continuing the departure climb
Communication *Applying intelligent reasoning to identify when and how to communicate with ATC and co-pilot*	Communicating with PM, including regarding gear up, flaps up, and potentially requesting clearance past 8000'.	• Observe physical actions (e.g., crew callouts): ○ Did the participant clearly communicate with the PM? ○ Did the participant ask the PM for help? If yes, what kind of help? ○ What information did the participant collect from their PM? From ATC? • Observe verbal indicators from protocol of communication: ○ What are participant reasons and reasoning for what they communicated?	• What was the basis for the callouts you made? • What was the influence of operator training and procedures on the callouts you made? • What was the influence of the generic checklist on the callouts you made? • I noticed you asked the PM for [X], could you talk a little more about why?

Scenario #3: Assessing Tradeoffs between Speed and Vertical Flightpath during Climb at a High Altitude

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Collect information from the PFD (VSI) and FMS (speed, altitude predictions). Collect information from PFD, ND, FMS, and EFB to look at the current lateral flightpath (waypoints, heading, constraints) and current vertical path (altitude, vertical speed, airspeed, thrust, and current FMAs).	• Observe physical actions to collect information: ○ What page in the FMS did the participant have open? ○ Did the participant appear to look at the FMS? • Observe verbal indicators from protocol of collecting information: ○ Did the participant say they used VSI? How accurately do they reference it? ○ Did the participant say they used airspeed? How accurately do they reference it? ○ Did the participant say they looked at altitude? How accurately do they reference it? ○ Did the participant say they looked at the time? How accurately do they reference it?	• What airspeed, altitude, and heading indications did you monitor your climb [NOTE: evidence of applying integration and estimation may emerge in responses to this question.] ○ Why did you monitor these indications? ○ If they do not say what indications but point or gesture, make sure to ask follow-up. ○ Ask detailed follow-up about as needed to clarify. • How did you prioritize the airspeed, altitude, and heading indicators you monitored? • Which airspeed, altitude, heading, and other flight deck indications did you use to make your decision regarding being able to meet ATC's request [NOTE: evidence of applying estimation, prediction and planning may emerge in responses to this question]. ○ If they do not say what indications but point or gesture, make sure to ask follow-up. ○ Ask detailed follow-up about as needed to clarify. • Was there anything else you were looking at?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine information from PFD and FMS with knowledge about aircraft performance. Combine collected information from PFD, ND, FMS, and EFB as well as environment to support understanding of where the aircraft should be in space, intended energy state, where the aircraft is actually going and its actual energy trend, and where the aircraft should be going and what it's energy trend should be.	• Observe physical actions indicating integrating integration: ○ [no physical actions that are clearly discernable] • Observe verbal indicators from protocol of integrating information: ○ What information did the participant combine to make their decision? VSI + airspeed + altitude + current time + knowledge	• How did you use information obtained from flight deck displays with any information from other resources to make your decision about being able to make ATC's request? • What knowledge did you use to help you make your decision? • How did you use information collected from flight deck displays to identify the impact on aircraft energy state? • What aircraft performance and aerodynamic knowledge did you apply to assess speed, vertical rate, and altitude tradeoffs?
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Roughly calculate required rate of climb to reach FL320 in the requested time. Perform rough calculations based on integrated information to judge aircraft's intended lateral and vertical trajectory in space and intended energy trend and how it incorporates constraints	• Observe physical actions indicating estimation: ○ Did the participant say yes or no to ATC? ○ How long did it take for the participant to respond to ATC? • Observe verbal indicators of estimation: ○ Did the participant apply any math or heuristics to make their decision of saying yes or no to ATC? ○ How did the participant utilize estimation when posed questions about a similar situation?	• How did you use airspeed, altitude, and heading indications to make your decision regarding being able to make ATC's request? • Why did you use these indicators to make your decision? • Did you use any mental math or shortcuts to make your decision? • What rules-of-thumb did you use? Why did you use this and what does it entail? • If ATC asked you at FL280, can you to make FL360 in five minutes or less, how would you assess if you could make it? • Let's say that when you were handed off to departure, they requested that you pass IZZO at FL220. How would you decide if you could make that constraint?
Prediction *Envision future events based on estimation of incomplete information in the present*	Utilize knowledge and potentially estimation (if estimation was performed) to predict whether aircraft will make it to FL320 in the requested time limit. Make additional projections of when aircraft should get to FL340 and how aircraft will respond past FL320, based on what the trend and trajectory of the aircraft should be, and modeling effects on	• Observe physical indicators of prediction: ○ Did the participant say yes or no to ATC? ○ If yes, did they make it to FL320 in time? ○ Did the participant revise their response? ○ Did the participant vocalize any justification for their response? • Observe verbal indicators from protocol of prediction: ○ Did the participant forecast effects of making the request on airspeed? Did they forecast these effects correctly? ○ How did the participant utilize prediction when posed questions about similar situations?	• What were (or would have been) the impacts on airspeed, energy, and the flightpath as a result of saying yes to ATC's request? • What were (or would have been) the impact of saying yes to the request on the rest of the flight?

	pitch, attitude, and speed as the aircraft executes climb.		
Planning *Formulate and identify a strategy, approach, and set of tasks or actions*	Determine and decide on action to adjust the flightpath and energy controls to make it to FL320 within the time limit. Determine and decide on action to adjust the flightpath and energy controls after passing FL320.	• Observe physical indicators of planning: ○ If the participant said yes, what adjustments did the participant make to the flight controls to execute their plan to make it to FL320? • Observe verbal indicators from protocol of planning: ○ How and why did the participant adjust any controls? ○ If the participant said no, do they plan for the effects of potentially staying at FL320?	• How did you (or how would you have) adjust autoflight systems to make the climb? • What would you have done if ATC did not clear you to FL340 and you had stayed at a lower than planned altitude?
Communication *Applying intelligent reasoning to identify when and how to communicate with ATC and co-pilot*	Communicating with PM about decision, response to ATC, and updates to flightpath.	• Observe physical actions of communication (e.g., crew callouts): ○ Did the participant clearly communicate with the PM? ○ Did the participant ask the PM for help? If yes, what kind of help? • Observe verbal indicators from protocol of communication: ○ What are participant reasons and reasoning for what they communicated?	• What was the basis for the callouts you made? • What was the influence of operator training and procedures on the callouts you made? • What was the influence of the generic checklist on the callouts you made?

Scenario #4: Managing Air Traffic Control (ATC) Interventions that Impact Flightpath Management (FPM) during En Route Cruise

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Gather information from the FMS (e.g., FUEL PRED page, extra fuel), release (alternate airport), and knowledge (aircraft performance, fuel burn). Collect information from PFD, ND, FMS, and EFB to look at the current lateral flightpath (waypoints, heading, constraints) and current vertical path (altitude, vertical speed, airspeed, thrust, and current FMAs).	• Observe physical actions to collect information: ○ Did the participant see the ACARS message? ○ Did the participant utilize the FUEL PRED page? (ALTN Time, Final/Time, Extra Time) ○ Did the participant ask for any information from ATC? What information did they ask for? ○ Did the participant ask for any information about weather? What information did they ask for? ○ Did the participant ask for any information about alternate or nearby airports? What information did they ask for? ○ Did the participant ask the PM for help in finding any information? • Observe verbal indicators from protocol of collecting information: ○ Was the participant able to collect the information they needed to assess their ability to hold and plan out the hold? ○ Did the participant demonstrate a solid understanding of entering hold and monitoring aircraft through hold maneuver?	• Did you have any challenges collecting the information you needed in order to program the hold in the box? • Did you have any challenges collecting the information you needed in order to know if you could hold for as long as you might have needed to? • If the participant indicated challenges (e.g., asked the PM for help, hesitated, etc.) inquire about those indications and what they were thinking, especially if they do not say they experienced any challenges. • What airspeed, altitude, and heading indications did you monitor once you started to enter the hold? Why did you monitor these?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine information from FMS and release with knowledge about aircraft performance. Combine collected information from PFD, ND, FMS, and EFB as well as environment to support understanding of where the aircraft should be in space, intended energy state, where the aircraft is actually going and its actual energy trend, and where the aircraft should be going and what it's energy trend should be.	• Observe physical actions indicating integrating integration: ○ Did the participant actions indicate utilizing multiple information sources? (e.g., requested weather and went to FUEL PRED page) • Observe verbal indicators from protocol of integrating information: ○ What information did the participant say they combined to understand whether they could hold and for how long?	[NOTE: evidence of applying estimation and prediction may emerge in answers to these questions] • How did you use information obtained from flight deck displays with information from other resources to enter the hold in the box? • How did you use information obtained from flight deck displays with information from other resources to decide how long you could hold for? • What knowledge did you use to program the hold? • How would you go about exiting the hold?
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Roughly calculate the fuel burn for time to expect to fly plus alternate plus reserve. Perform rough calculations based on integrated information to judge aircraft's intended lateral and vertical trajectory in space and intended energy trend and how it incorporates constraints.	• Observe physical actions indicating estimation: ○ Did the participant accept the hold? ○ Did the participant exhibit any hesitation in accepting the hold? ○ Did the participant ask for information about weather, the alternate airport, or other nearby airports? ○ How did the participant respond to information about nearby airports being unavailable? • Observe verbal indicators from protocol of estimation: ○ Did the participant know how long they can hold for? ○ How did the participant apply any math or heuristics to determine how long they could hold for?	• Did you identify how long you could hold for? • How long can you hold for? • How did you figure that out? ○ [If mentioned using FMS functions], how did you know that the FMS was correct? ○ Follow-up if they do not mention FMS to ascertain what information they used and how they used it. • How was weather a consideration?
Prediction *Envision future events based on estimation of incomplete information in the present*	Utilize knowledge and potentially estimation (if estimation was performed) OR use just FMS to predict if have enough fuel to hold or if want to go to alternate. Make additional projections and predictions regarding entering the hold to manage entering the hold.	• Observe physical indicators of prediction: ○ Did the participant take any action after receiving the ACARS message? What action did they take? ○ Did the participant ask for information about weather, the alternate airport, and other nearby airports? What information do they request? ○ Did the participant request information from ATC? What information do they request? • Observe verbal indicators from protocol of prediction:	• If the scenario had continued, would you have stayed in the hold for the whole 55 minutes that you were told to expect? Why or why not? • When would you have considered going to the alternate? Why? • How would have staying in the hold for the whole 55 minutes have affected your descent in terms: ○ Fuel burn ○ Performance ○ Making it to an alternate

		○ Was the participant thinking ahead (predicting) implications on flightpath of holding for the whole 55 minutes?	
Planning *Formulate and identify a strategy, approach, and set of tasks or actions*	Determine and decide on action to accept hold or not. Prepare if accepting hold for alternative actions if hold is longer than expected.	• Observe physical indicators of planning: ○ Did the participant ask for information about weather, the alternate airport, and other nearby airports? What information do they request? ○ Did the participant request information from ATC? What information do they request? ○ Did the participant verbalize a plan for the hold? • Observe verbal indicators from protocol of planning: ○ Did the participant know what they would have done as a result of holding?	• Did you have a plan for how long you would hold for? If yes, what was the plan and why did you have this plan. If no, why not. • Were operator procedures a consideration in your decision about the alternate?
Communication *Applying intelligent reasoning to identify when and how to communicate with ATC and PM*	Communicating with PM about decision, response to ATC, and updates to flightpath.	• Observe crew callouts: ○ Did the participant verbalize to the PM their thoughts (and if they had a plan) regarding the hold? ○ What information did the participant collect verbally? • Observe verbal indicators from protocol of communication: ○ What are participant reasons and reasoning for what they communicated?	• What was the basis for the callouts you made? • What was the influence of operator training and procedures on the callouts you made? • What was the influence of the generic checklist on the callouts you made?

Scenario #5: Energy Management during RNAV Arrival Descent to Los Angeles (KLAX)

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Gather data from the PFD, ND, FMS, and EFB to look at the current lateral flightpath (waypoints, heading, constraints) and current vertical path (altitude, vertical speed, airspeed, thrust, and current FMAs). Look out the window and at the EFB / ND for wind, weather, traffic and insight into aircraft state.	• Observe physical actions to collect information: ○ Did the participant use the F-PLN page in the FMS? ○ Did the participant use the DESC (VDEV) when they were in NAV mode or HDG mode to see vertical deviation? ○ Did the participant have CSTR enabled? ○ Did the participant put speed brakes on before or after “More Drag”? • Observe verbal indicators from protocol of collecting information: ○ Did the participant see the “More Drag” message? ○ Did the participant see any amber stars on constraints? ○ Did the participant say they used VSI? ○ Did the participant say they looked at VDEV and where did they look at it (DESC or on Altitude scale)?	• What airspeed, altitude, and heading indications did you monitor during the arrival? • How did you prioritize the airspeed, altitude, and heading indicators you monitored during the arrival? • What did you look at to monitor your vertical flightpath? • Did you see a “More Drag” message during the arrival? • Was there anything else you were looking at during the arrival? ○ Why or why not? • Were you looking at anything on the FMS during the arrival? Why? What does it mean? • Did you use the EFB during the arrival?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine collected information from PFD, ND, FMS, and EFB as well as environment (wind). Collected information should support pilot understanding of where the aircraft should be in space and what the energy state should be, where the aircraft is actually going and its actual energy trend, and where the aircraft should be going and what it's energy trend should be (e.g., to make constraints).	• Observe physical actions indicating integrating integration: ○ Did the participant put speed brakes on before or after “More Drag”? • Observe verbal indicators from protocol of integrating information: ○ What information did the participant say they combined to manage the arrival?	• How did you use knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath and energy state during the arrival?
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Perform rough calculations based on integrated information to judge aircraft's intended lateral and vertical trajectory in space and intended energy trend and how it incorporates constraints.	• Observe physical actions indicating estimation: ○ Did the participant deploy speed brakes prior to the “More Drag” notification? ○ When/where did the participant put speed brakes back down? • Observe verbal indicators of estimation: ○ Did the participant realize the role of the tailwind in the descent? ○ Was the participant utilizing any mental calculations to know when they were engaging/disengaging speed brakes?	• You mentioned using [airspeed, altitude, heading indications] to monitor your descent. Can you elaborate on how you used these [indications]? [brackets reference specifically referring to how they answered “Collection” question] • You put speed brakes on [reference when they enabled speed brakes]. Why did you put the speed brakes on at that point in time? • Did wind appear to affect your descent at all?
Prediction *Envision future events based on estimation of incomplete information in the present*	Make projections of when aircraft should get to next fix based on what the trend and trajectory of the aircraft should be, project meeting of constraints based on intended trajectory, and effects of weather (wind).	• Observe physical indicators of prediction: ○ What modes does the participant utilize during the descent? • Observe verbal indicators from protocol of prediction: ○ Did the participant predict that it might be challenging to meet the constraints on the descent? [in addition to answer to verbal protocol, reference pre-brief and approach briefing] ○ Did the participant say they anticipated needing speed brakes? ○ To what extent did the participant exhibit an understanding of why speed brakes was needed (e.g., balance between altitude and airspeed)?	• Did the arrival go as you expected it go when you briefed it? Why or why not? • Did you anticipate you would need speed brakes when you received the speed reduction from ATC? Why or why not? • [Depending on answers to previous questions] Did you put on speed brakes when you saw the “More Drag” message”? Were you aware you were fast prior to seeing that message?
Planning *Formulate and identify a strategy, approach, and set of tasks or actions*	Develop plan for adjusting or updating flightpath management targets based on estimations and predictions. Determine and decide on action to adjust the flightpath and	• Observe physical indicators of planning: ○ What modes did the participant utilize to manage flightpath on the arrival? • Observe verbal indicators from protocol of planning:	• For how long did you deploy speed brakes? • What speed brake selection did you choose? Why? • You used [which mode they used, NAV, HDG, etc.]. Can you talk about why you used this mode?

	energy controls based on comparison of actual vertical position, actual lateral position, and actual energy state to intended and comparison of actual vertical trajectory, actual lateral trajectory, and actual energy trend to intended/expected.	○ Did the participant have a plan for how and when they deployed speed brakes? ○ Did the participant have a plan or strategy regarding the modes they used to meet the speed constraint?	• When you were able to resume published speeds, you resumed speeds by [reference what they do]. Can you talk about why you resumed speeds this way? • [If they did not make a constraint], when did you realize you would not make a published restriction?
Communication *Applying intelligent reasoning to identify when and how to communicate with ATC and PM*	Brief the approach using mental model as foundation for communicating expectations. Referencing may include potentially putting the Nav display in various modes and/or reviewing various pages in the FMS. Communicating with PM.	• Observe crew callouts: ○ Did the participant clearly communicate with the PM? ○ Did the participant ask the PM for help? If yes, what kind of help? • Observe verbal indicators from protocol of communication: ○ What are participant reasons and reasoning for what they communicated? ○ How did differences in calling out FMAs affect the participant?	• How did callouts about FMAs affect your flightpath management in the arrival? For example, you did not have callout of mode changes by the PM. How did this affect your flightpath management in the arrival? • What was the basis for the callouts that you made in the arrival? • What was the influence of operator training and procedures on the callouts you made? • What was the influence of the generic checklist on the callouts you made?

Scenario #6: Navigation Source Transition during Arrival-to-Approach Operations

Cognitive Skills	Tasks and Knowledge	Potential Indicators of Decay and Degradation	Verbal Protocol
Collection *Seek and recognize information as it is related to an acquired schema (knowledge one already has)*	Gather data from the PFD, ND, FMS, and EFB to look at the current lateral flightpath (RWY indicator, heading) and current vertical path (altitude, vertical speed, airspeed, thrust, and current FMAs). Look out the window and at the EFB / ND for wind, weather, traffic and insight into aircraft state.	• Observe physical actions to collect information: ○ Did the participant utilize the APPR page? ○ Did the participant have CSTR enabled? • Observe verbal indicators from protocol of collecting information: ○ Does the participant reference use the FMAs? ○ Does the participant reference use the PAPI lights?	• What airspeed, altitude, and heading indications did you monitor during the approach? Landing? • How did you verify or check that the navigation source had transitioned successfully? • How did you prioritize the airspeed, altitude, and heading indicators you monitored during the approach? Landing? • Was there anything else you were looking at during the approach? Landing? ○ Why or why not? • Were you looking at anything on the FMS during the arrival? Why? What does it mean? • Did you use the EFB during the approach? Landing?
Information integration *Put multiple pieces of information together towards an idea, concept, solution*	Combine collected information from PFD, ND, FMS, and EFB as well as environment. Collected information should support pilot understanding of where the aircraft should be in space and what the energy state should be, where the aircraft is actually going and its actual energy trend, and where the aircraft should be going and what it's energy trend should be.	• Observe physical actions indicating integrating integration: ○ When did the participant arm the approach? • Observe verbal indicators from protocol of integrating information: ○ What information did the participant say they combined to manage the approach?	• How did you use out-the-window visual cues, knowledge, and other resources at your disposal with information obtained from flight deck displays to monitor your flightpath and energy state during the approach? Landing? • How did you prioritize your attention between out-the-window visual cues and information obtained from flight deck displays? • Did how you prioritized your attention change throughout the approach? Why/why not? ○ If it remains unclear how they transitioned attention, ask follow-up.
Estimation *Form judgements of when airplane might get to next fix, traffic positions of other aircraft, effects of changes to plan by ATC on current trajectory, and effects of traffic on current flightpath.*	Perform rough calculations based on integrated information to judge aircraft's intended lateral and vertical trajectory in space and intended energy trend. Estimation to help anticipate arming approach, turning off autopilot.	• Observe physical actions indicating estimation: ○ When did the participant disengage autoflight? • Observe verbal indicators of estimation: ○ Did the participant indicate any kind of mental reasoning (e.g., estimation) regarding weather, or any other considerations? ○ When the participant was observing indicators, were they actually thinking or performing any form of estimation of flightpath based on indicators? Or were they passively consuming?	• You mentioned using [airspeed, altitude, heading indications] to monitor your approach. Can you elaborate on how you used these [indications]? [brackets reference specifically referring to how they answered "Collection" question] • Did you consider how weather might impact your approach and landing? • How did you determine if flightpath and speed deviations were correctable at 1,000'? At 500'? At the threshold crossing? • What parameters would have led you to initiate a go around? (e.g., what is the stable criteria applied by your operator)
Prediction *Envision future events based on estimation of incomplete information in the present*	Make projections to anticipate when aircraft will intercept ILS localizer and glideslope. Projections should include modeling effects on pitch, attitude, and speed as the aircraft should execute maneuvers.	• Observe physical indicators of prediction: ○ Did the participant have their hand up to the MCP in anticipation? • Observe verbal indicators from protocol of prediction: ○ Did the participant predict or think ahead about the flightpath?	• How did you verify that the performance of the aircraft was what you were expecting to get in regard to: ○ vertical flightpath ○ lateral flightpath ○ speed • Were you anticipating any changes to the approach that could affect the flightpath? Why or why not?
Planning *Formulate and identify a strategy, approach, and set of tasks or actions*	Determine and decide on action (as needed) to adjust the flightpath and energy controls based on comparison of actual vertical position, actual lateral position, and actual energy state to intended and comparison of actual vertical trajectory, actual lateral	• Observe physical indicators of planning: ○ When did the participant arm the approach? • Observe verbal indicators from protocol of planning: ○ Observe crew callouts related to establishing targets for airspeed, altitude, thrust, and trajectory (tactical planning based on changing situation) ○ How did the participant make decisions about disengaging autoflight systems, deciding to continue approach? [was it training, rote action/procedure, conscious thought]	• What information did you use to make decisions to: ○ Disengaging autopilot ○ Disengaging autothrottle ○ Continuing approach

	trajectory, and actual energy trend to intended/expected.		
Communication *Applying intelligent reasoning to identify when and how to communicate with ATC and PM*	Communicating with PM.	• Observe crew callouts: ○ Did the participant clearly communicate with the PM? ○ Did the participant ask the PM for help? If yes, what kind of help? • Observe verbal indicators from protocol of communication: ○ What are participant reasons and reasoning for what they communicated? ○ How did differences in calling out FMAs affect the participant?	• How did callouts about FMAs affect your flightpath management in the approach? For example, you did not have callout of mode changes by the PM. How did this affect your flightpath management in the approach? • Related to that, what communications do your normally expect that can facilitate making a stable approach (i.e., challenge/response communications) and how do you think that affected your flightpath management? • What was the basis for the callouts that you made in the approach? • What was the influence of operator training and procedures on the callouts you made? • What was the influence of the generic checklist on the callouts you made?

APPENDIX K – LONGITUDINAL STUDY - FLIGHT RELEASES

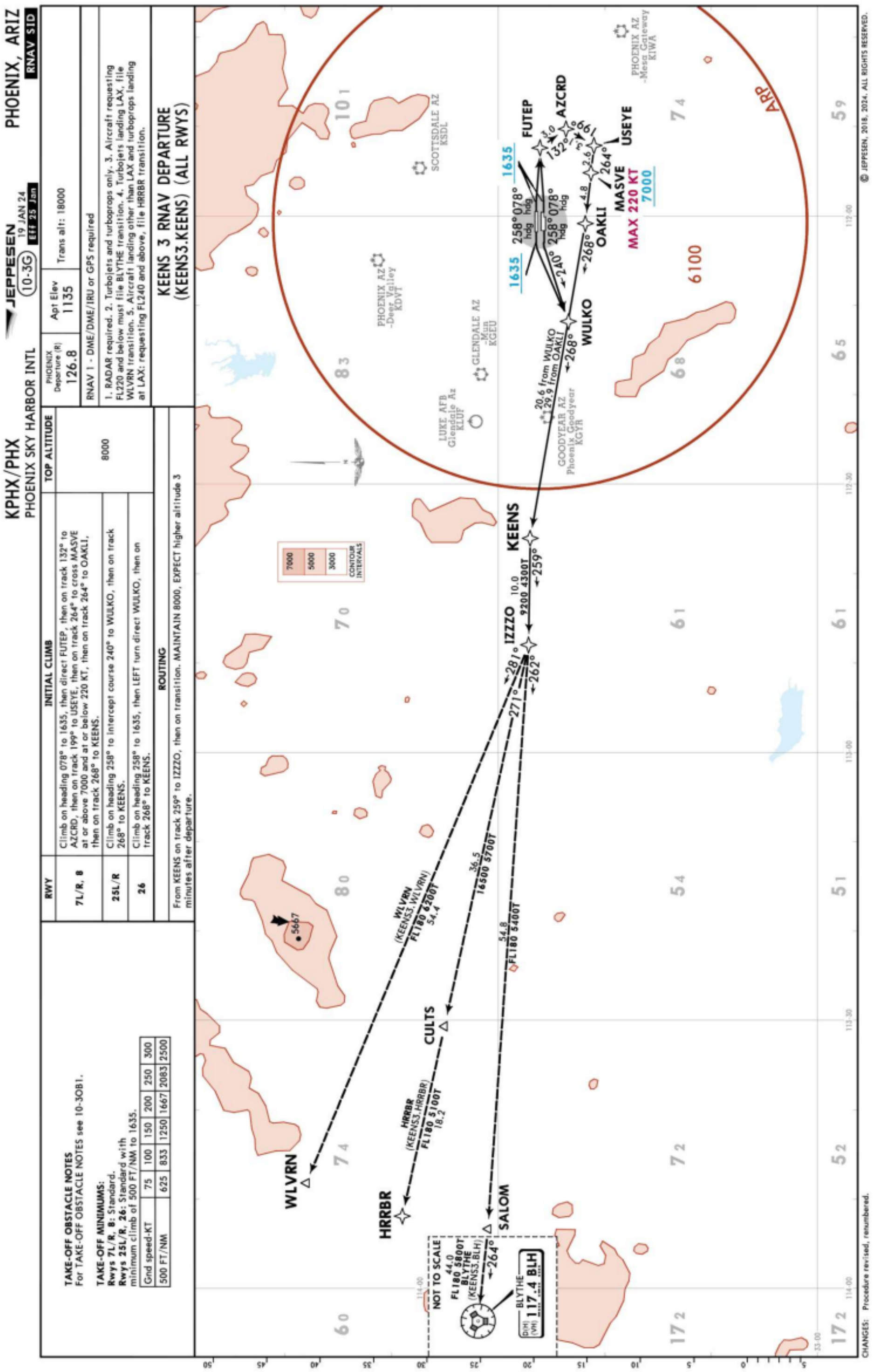
2.ReleasePerfData_A320.pdf

2.ReleasePerfData_B737.pdf

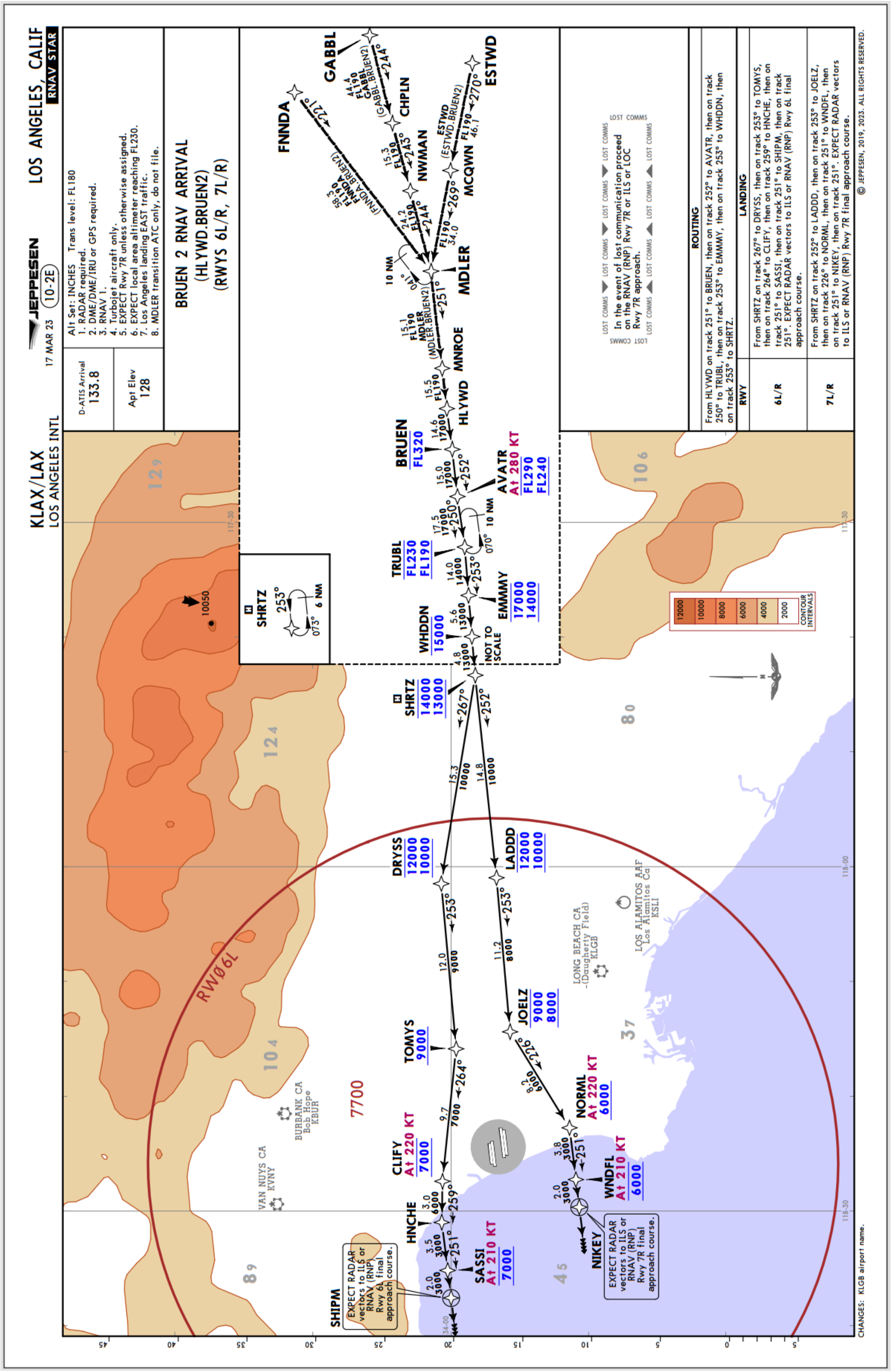
APPENDIX L – LONGITUDINAL STUDY - CHARTS

For KPHX (Phoenix Airport) and KLAX (Los Angeles Airport) (see Appendix D)

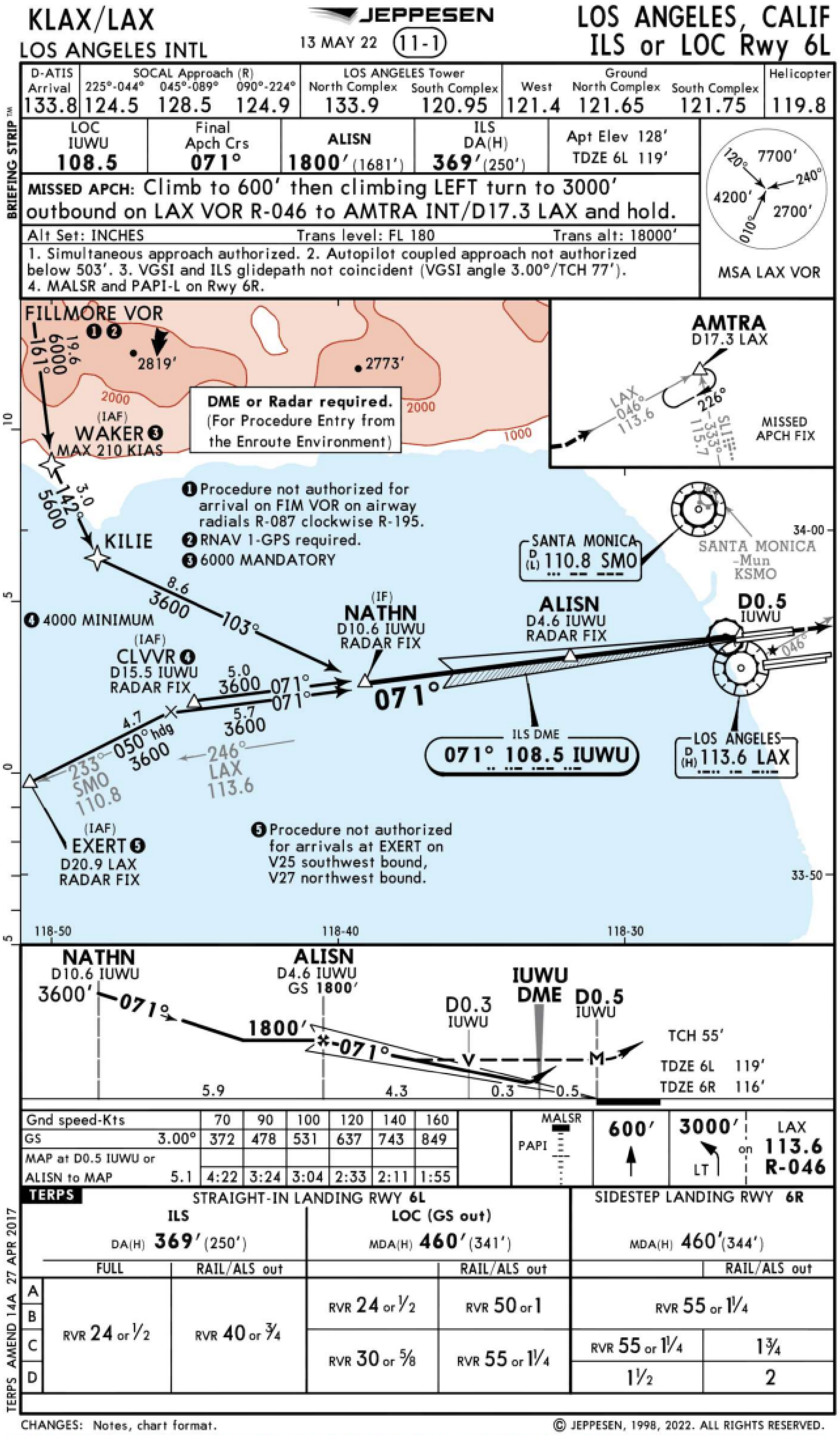
RNAV Departure – KEENS3



RNAV Arrival – BRUEN2



ILS Approach Runway 6L



APPENDIX M – LONGITUDINAL STUDY - ATC

Scenario 1: No ATC

Scenario 2: Clearance provided by experimenter (Nichola)

Scenario 3:

[Holding short of runway 7L]
Pilot: requests takeoff clearance…
ATC: MAC689, winds 030 at 10 knots, RNAV to FUTEP, clear for takeoff Rwy 7L

[2500 feet MSL after takeoff, switch to departure]
ATC: MAC689 contact departure 126.8.

[when pilot checks in with departure]
ATC: MAC689, radar contact

[only when pilot requests higher]
ATC: MAC689, climb and maintain FL220.

Scenario 4:

[20,000 feet]
ATC: MAC689 contact Albuquerque center 135.15.
Pilot: Checks in
ATC: MAC689 Albuquerque center roger climb and maintain flight level 320.

[at FL260]
ATC: MAC689 Albuquerque center, climb and maintain flight level 340; I need you through flight level 310 in **three** minutes or less for traffic, let me know if you can't make it.

- If the pilot says they are unable to make it – level them at FL280 or closest altitude for 1 min, then clear them to FL340.
- If the pilot asks if they can slow down to make it, allow them to do that.
- If the pilot requests something different (e.g., for more time or different altitude to make request) – deny request and level them at FL280 or closest altitude for 1 min.

Scenario 5:

When Scenario 4 is loaded, check with CAE engineer that the aircraft is logged into KUSA so the ACARS message will go through.
[crossing point ESTWD]
ATC: MAC689 contact Los Angeles center on 127.52.

[30 miles to MCQWN]
ACARS message is sent.
If there is an issue with sending the ACARS message, make the following radio call:
ATC: MAC689, heavy traffic into KLAX due to weather, expect delays on the arrival.

[Crossing ETP – waypoint on display, ~10 miles after MCQWN, 25 miles to MDLER]
ATC: MAC689, LA Center, I have holding instructions, advise when ready to copy.
Pilot: MAC689, ready to copy

ATC: MAC689, hold as published at MDLER, FL340; expect further clearance @time [add 55 minutes to the time, convert to ZULU]

- Local sim time is shown on the lower left corner of the bottom screen. Convert to Zulu, then add 55 mins.
- If pilot asks for NON-published HOLD, say NO.
- Approve pilot requests to slow down early or adjust the holding pattern (leg distance, inbound radial, etc.)
- If the pilot requests clearance to divert, respond with "standby for coordination."
- If the pilot cannot enter the hold, then give them vectors…
    - "Fly heading 041, expect vectors until further clearance in 50 minutes."

Scenario 6 and 7:

Do not allow the aircraft to descend early. If they ask, tell them unable due to crossing traffic underneath.

[**at TOD]**
ATC: MAC689 descend via the BRUEN2 for Rwy 6L, altimeter 30.00. Best forward speed to BRUEN.

- TOD occurs after HLYWD.
- If the pilot asks for clearance for the arrival earlier than TOD, state: "MAC 689, expect clearance in X miles" and estimate based on location of HLYWD.

[crossing point BRUEN]
ATC: MAC689 Los Angeles Center contact SoCal approach on 124.0
Pilot: Checks in
ATC: MAC689, SoCal approach, expect ILS runway 6L.

[10 NM to AVATR]
ATC: MAC689, slow to 250 all the way to DRYSS. Resume published speeds at DRYSS.

- If pilot says they cannot make the altitudes, tell them "MAC 689, SoCal approach, maintain 250 and do your best on the altitudes."

[crossing point SASSI]
ATC: MAC689 descend and maintain 3000, heading 250.

[15 seconds past NATHN or ~2 NM]
ATC: MAC689 turn left heading 160, slow to 180 knots.

[~2.5NM from final approach course]
ATC: MAC689 turn left heading 090, maintain 2000 until established on the localizer cleared ILS RW 6L.

[2 mi to ALISN]
ATC: MAC689 contact Los Angeles tower on 120.95.
Pilot: Checks in
ATC: MAC689 Los Angeles tower, winds 360 at 10, cleared to land RW 6L.
ATC: MAC689, right when able, contact ground 121.75.

If pilot asks for alternate climb-out procedures…
ATC: "fly runway heading, climb and maintain 3000 ft, expect vectors"

APPENDIX N – VERBAL ANALYSIS: COUNTS & GRAPHS

Verbal analysis was used to qualitatively assess the cognitive skills and knowledge of the pilot participants. This involved coding for cognitive skills and knowledge; aggregation of the counts of these codes is provided below. The raw frequency counts of the coded data are provided in Table 22.

Table 22. Means and standard deviations for baseline rates of cognitive skills.

Skill	Group	A320				B737			
		Verbal Protocol		Scenarios		Verbal Protocol		Scenarios	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Communication	Current	33	9.1	57	3.8	30	5.4	39	6.0
	6-12 month	40	5.2	74	15.3	37	9.6	44	7.2
	12-24 month	42	4.19	78	17.2	41	10.0	59	13.5
Collection	Current	165	14.3	75	1.7	119	8.4	63	9.0
	6-12 month	191	12.0	90	15.8	132	5.6	54	16.5
	12-24 month	176	14.57	72	15.0	97	8.9	47	17.4
Integration	Current	47	8.	25	6.2	38	14.2	19	6.4
	6-12 month	71	13.1	43	16.9	55	16.2	29	7.0
	12-24 month	65	4.4	33	14.7	52	11.2	24	3.1
Estimation	Current	58	5	10	3.4	49	7.1	12	4.4
	6-12 month	57	12	13	9.5	46	2.1	22	3.8
	12-24 month	54	15	13	4.2	44	4.0	19	3.1
Prediction	Current	65	13.2	11	4.2	40	8.0	11	6.0
	6-12 month	62	8.9	9	3.6	39	13.2	8	3.5
	12-24 month	59	8.4	9	3.7	32	11.6	9	3.5
Planning	Current	59	17.6	7	2.9	41	9.1	6	9.3
	6-12 month	57	16.76	16	7.5	42	10.8	9	4.0
	12-24 month	54	6.9	10	4.1	38	5.9	10	17.7

During coding, a trend was noticed in the communications, where participants in the 12-24 month group seemed to communicate more than those in the 6-12 and current groups. This prompted an analysis of the different types of communications participants engaged in. Figure 24 depicts average counts for the different types of communication behaviors by A320 participants and Figure 25 shows the average counts for the B737 participants. Participants who had been away from flying tended make more requests for assistance, more requests to repeat information or clarify information, more statements that indicated they had a weak mental model, and they tended to share more information about the state of the aircraft. Combining both the A320 and B737 participants who had been away from flying for 12-24 months, these participants engaged in 64% less social dialogue than current pilots.

Cross-Sectional Study findings based on 12 A320 participants flying from Phoenix (KPHX) to Los Angeles (KLAX)

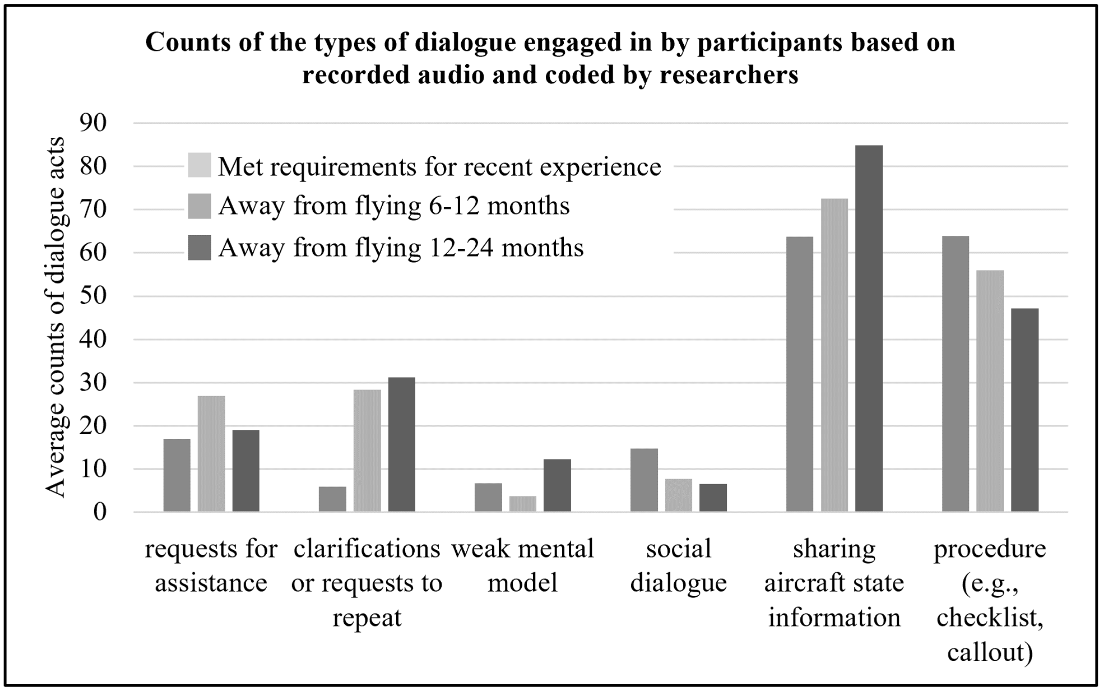


Figure 24. Average counts of types of dialogue engaged in by A320 participants.

Cross-Sectional Study findings based on 12 B737 participants flying from Phoenix (KPHX) to Los Angeles (KLAX)

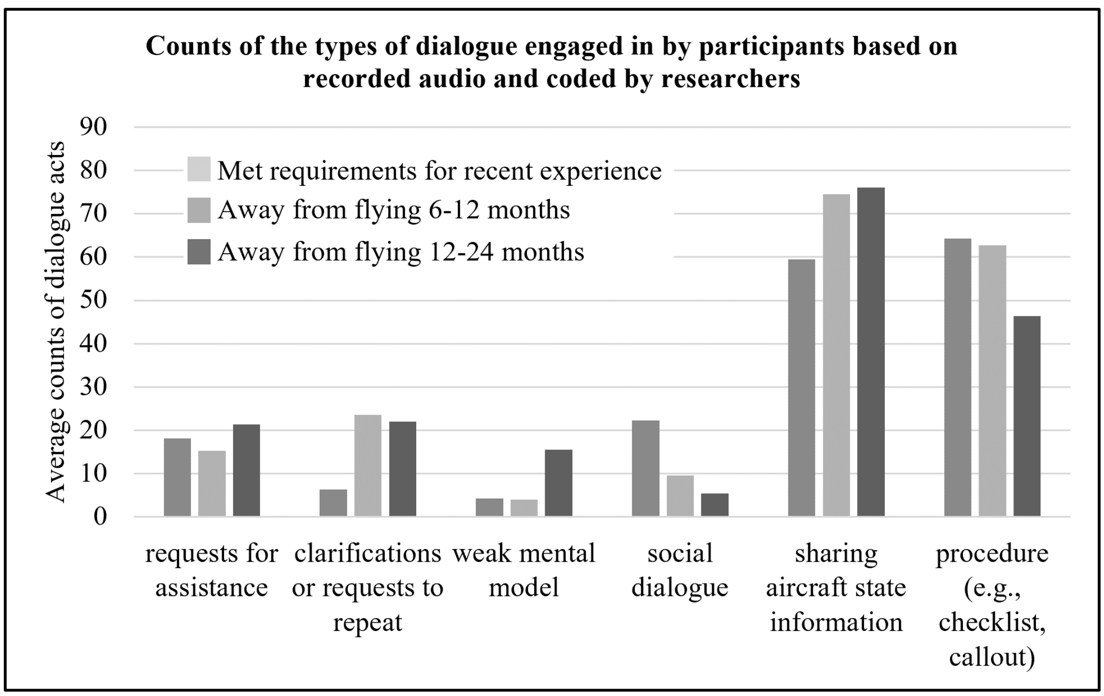
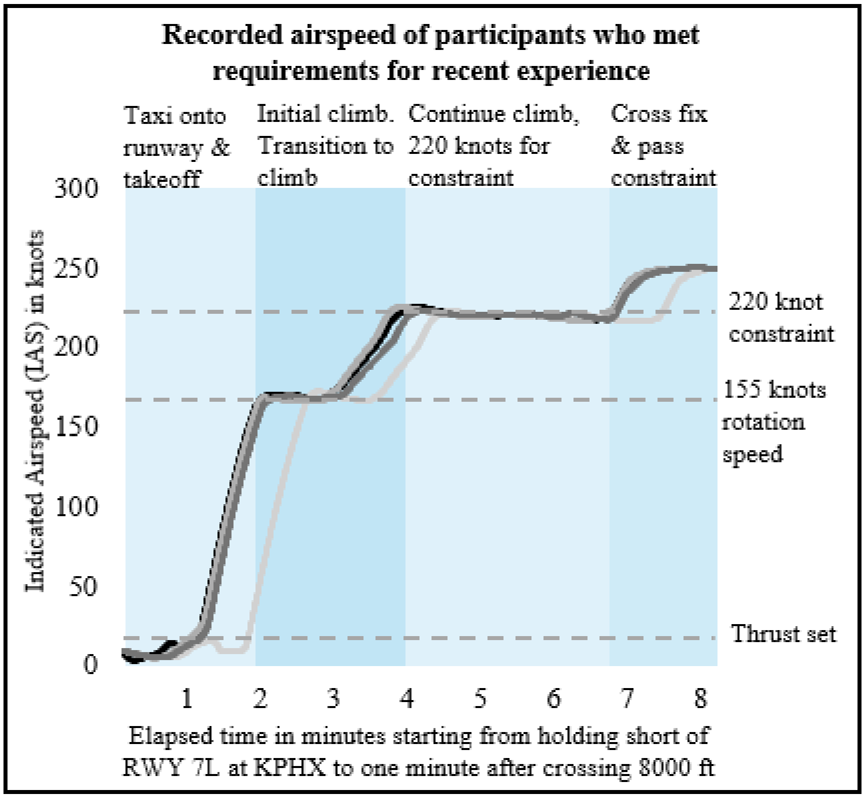


Figure 25. Average counts of types of dialogue engaged in by B737 participants.

APPENDIX O – INDIVIDUAL GRAPHS

A320 speed management during takeoff and climb

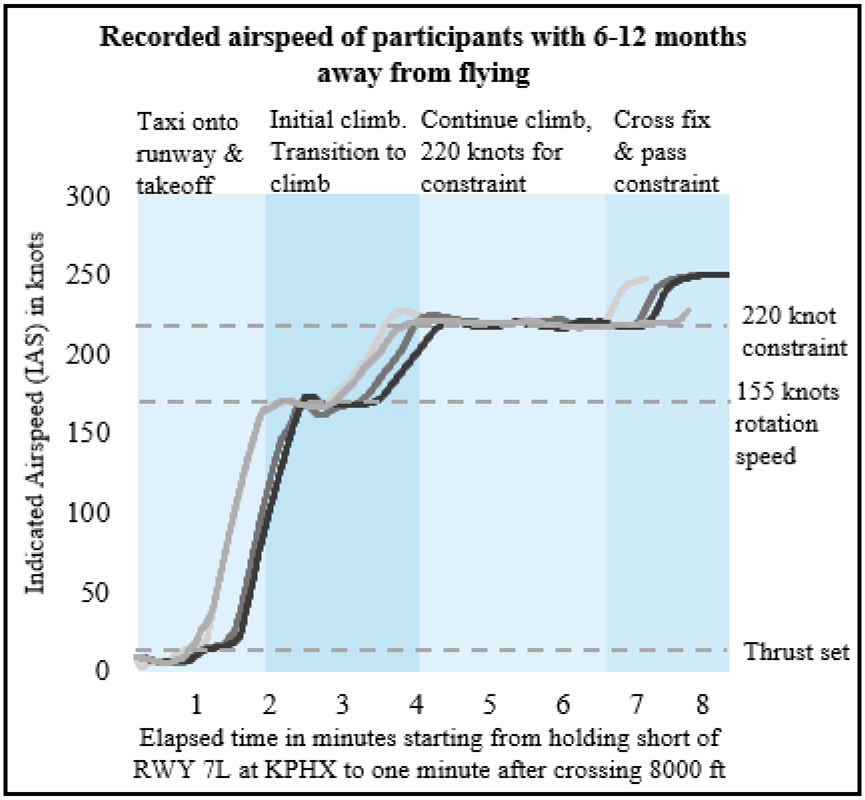
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 speed management during takeoff and climb

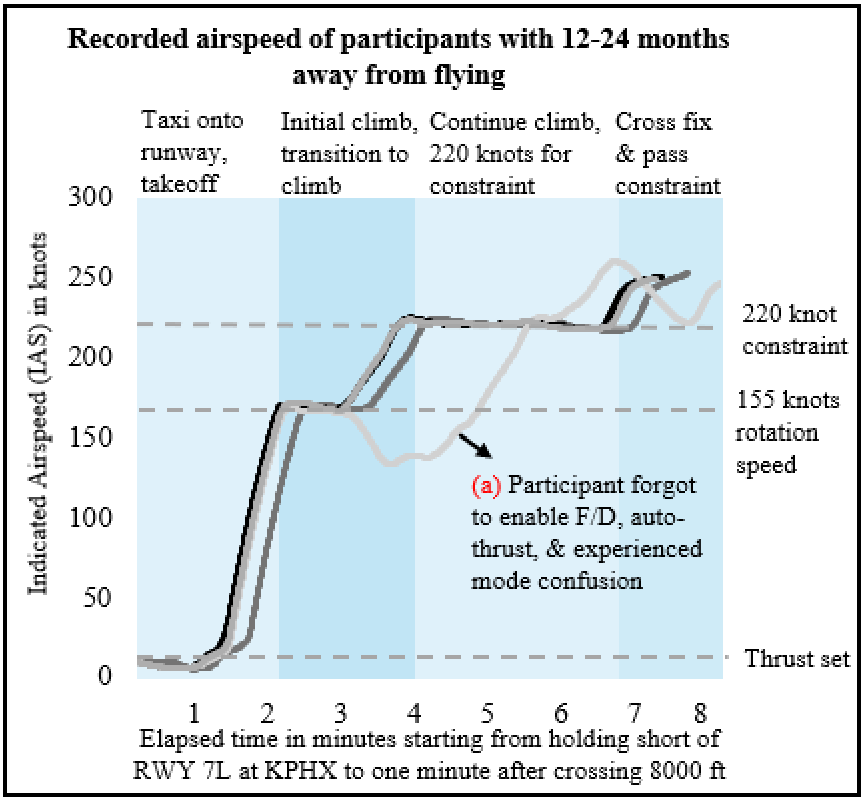
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 speed management during takeoff and climb

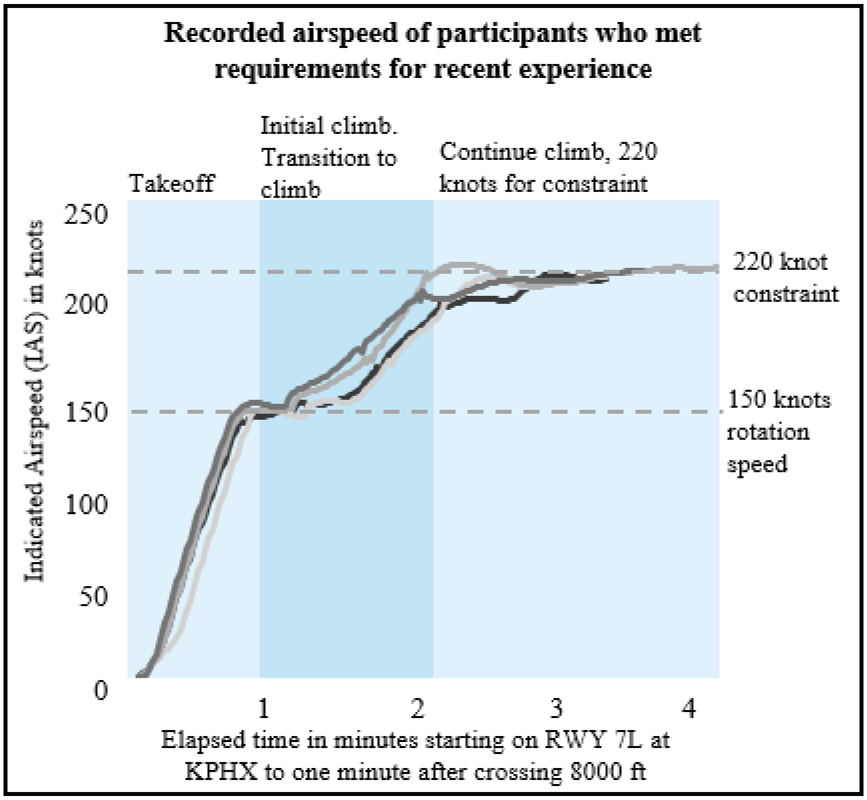
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 speed management during takeoff and climb

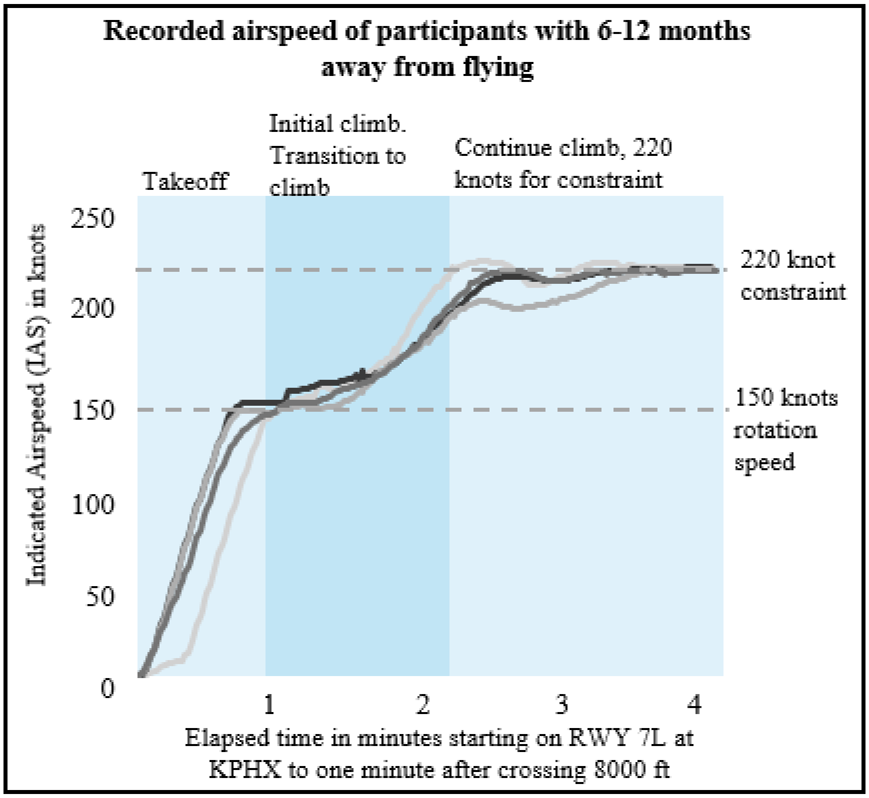
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of B737 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 speed management during takeoff and climb

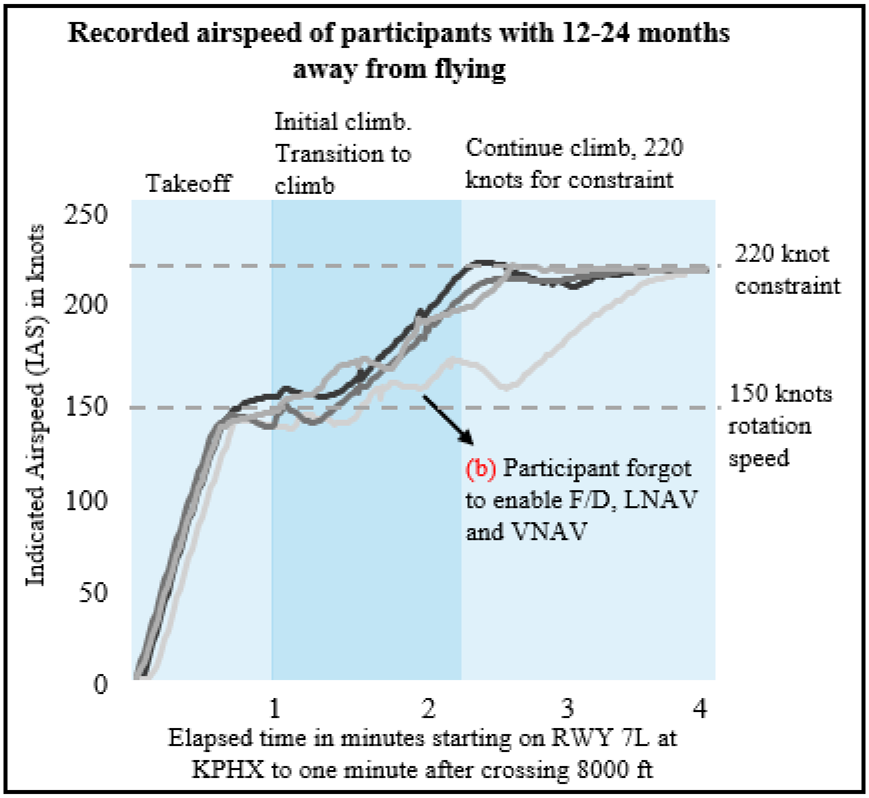
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of B737 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 speed management during takeoff and climb

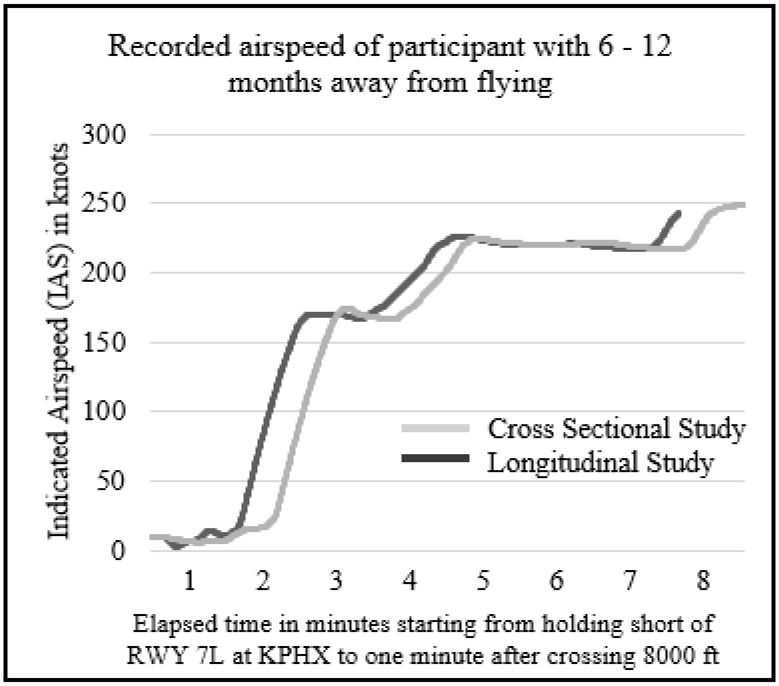
Cross-Sectional Study findings based on 12 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



25% (n = 4) of B737 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 speed management during take-off and climb in Longitudinal Study

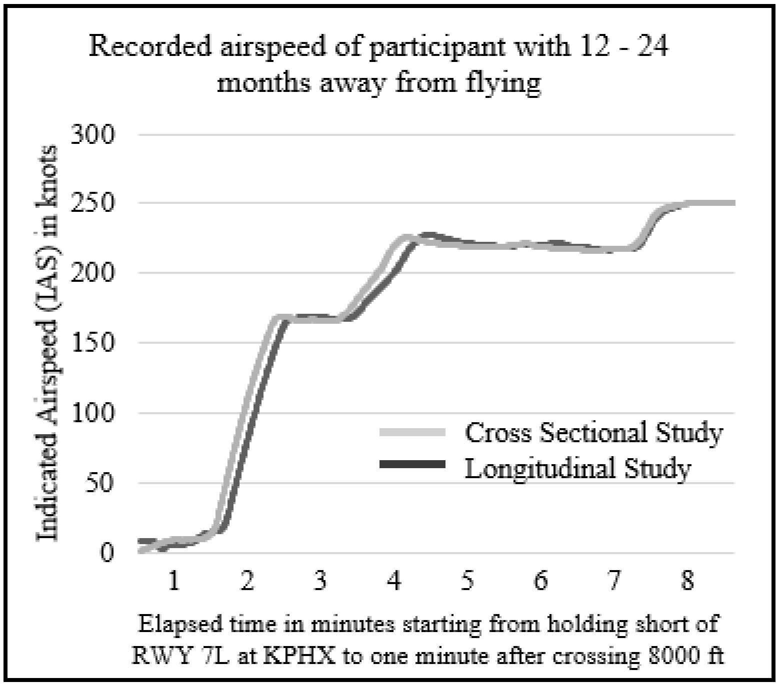
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 6-12 months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 speed management during take-off and climb in Longitudinal Study

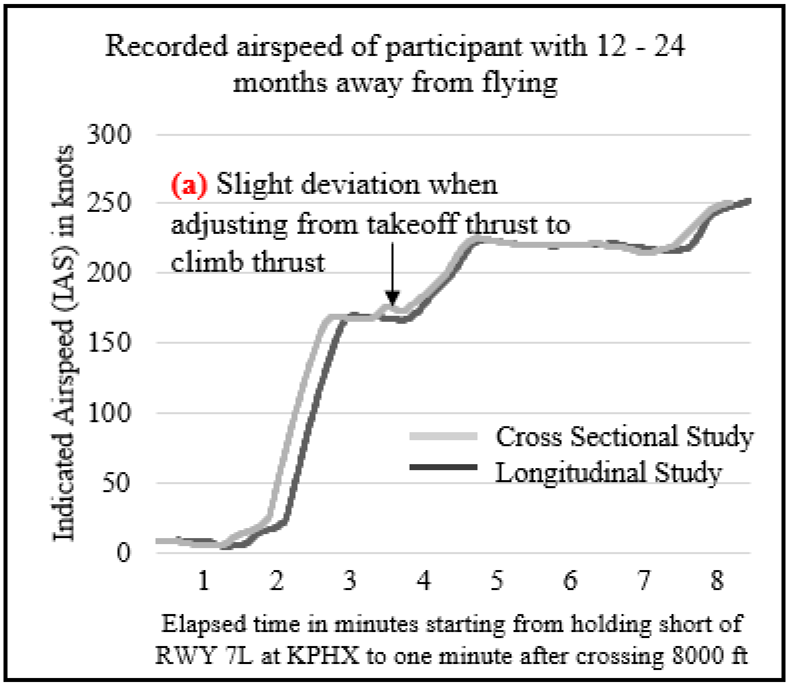
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 12-24 months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 speed management during take-off and climb in Longitudinal Study

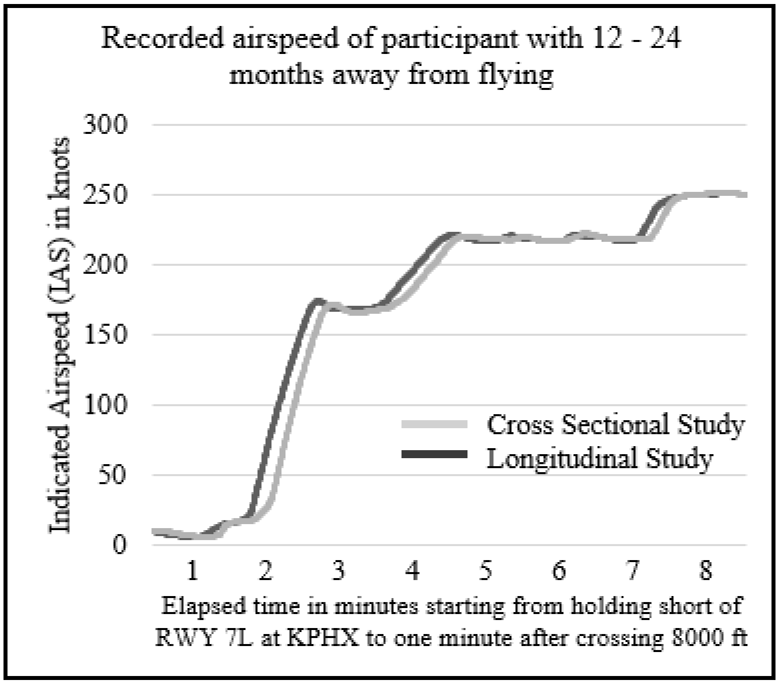
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 12-24 months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 speed management during take-off and climb in Longitudinal Study

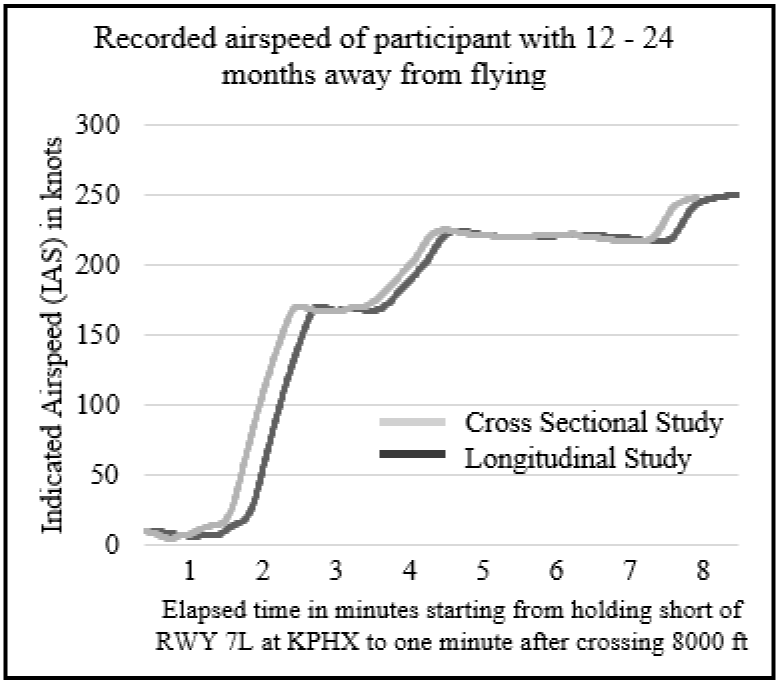
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 6-12 months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 speed management during take-off and climb in Longitudinal Study

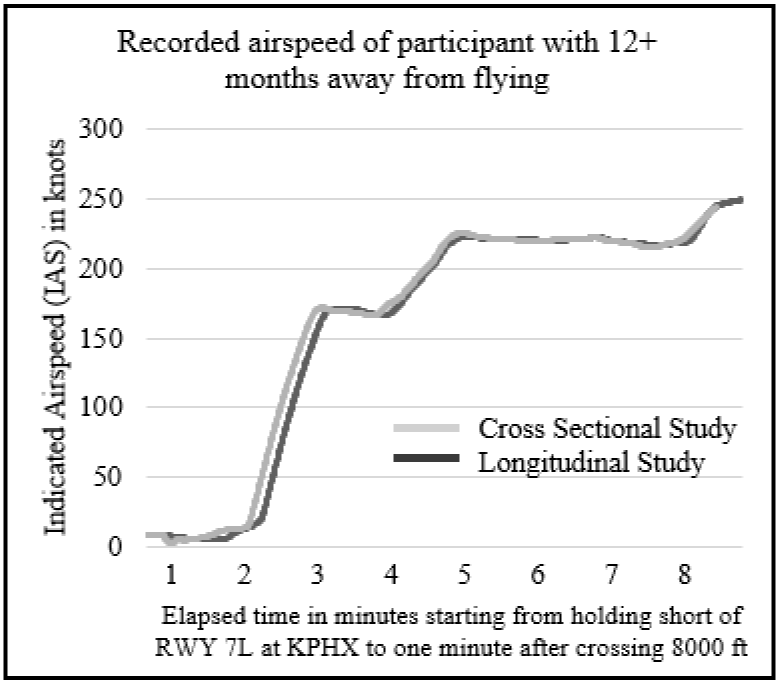
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 12-24 months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 speed management during take-off and climb in Longitudinal Study

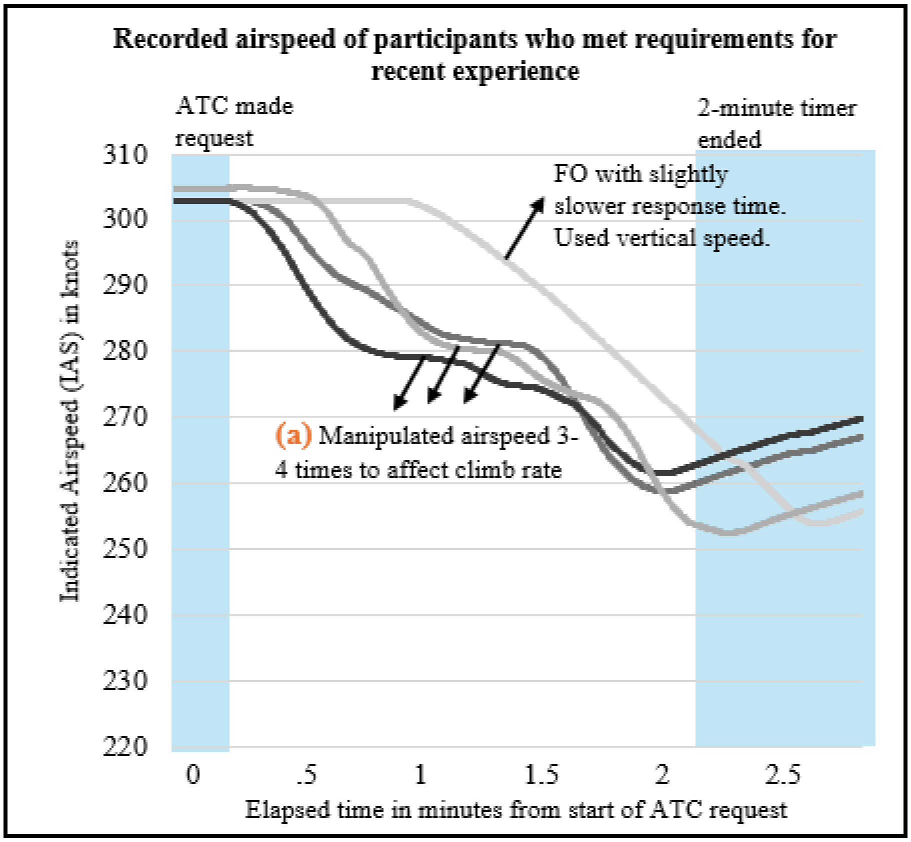
Longitudinal findings based on 6 participants flying the KEENS Area Navigation (RNAV) Departure from runway 7L from Phoenix (KPHX)



One A320 participant (n = 1) with 24+ months away from flying on the day of the Longitudinal Study data collection. Six (n=6) participants total completed the Longitudinal Study.

A320 airspeed in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

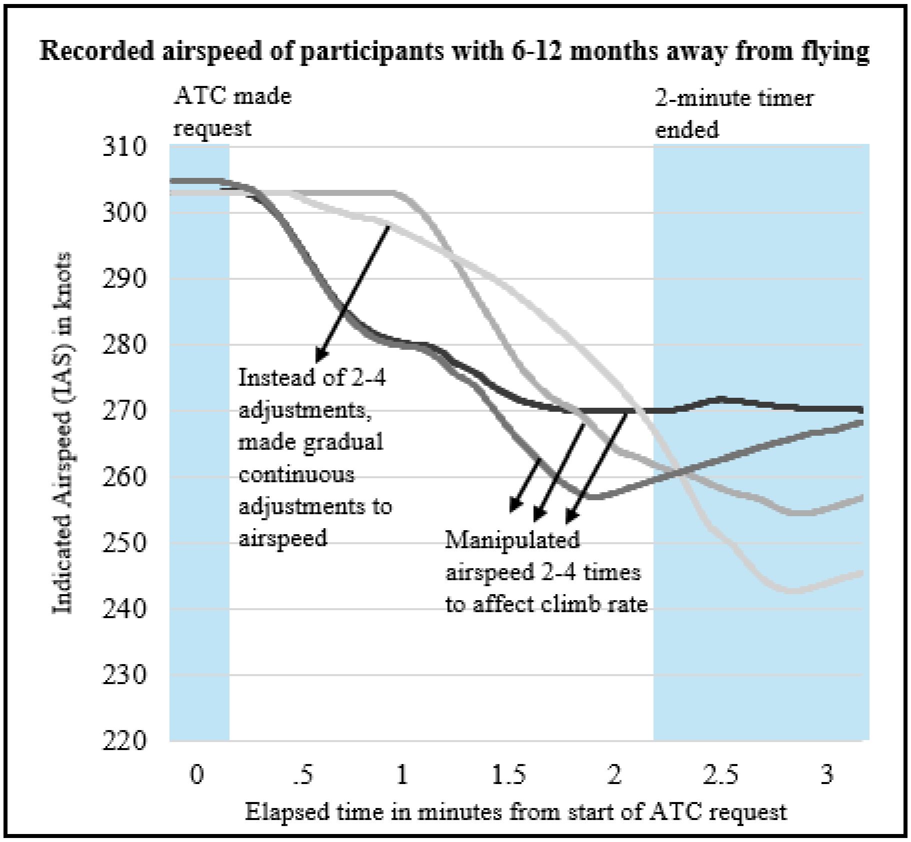
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 airspeed in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

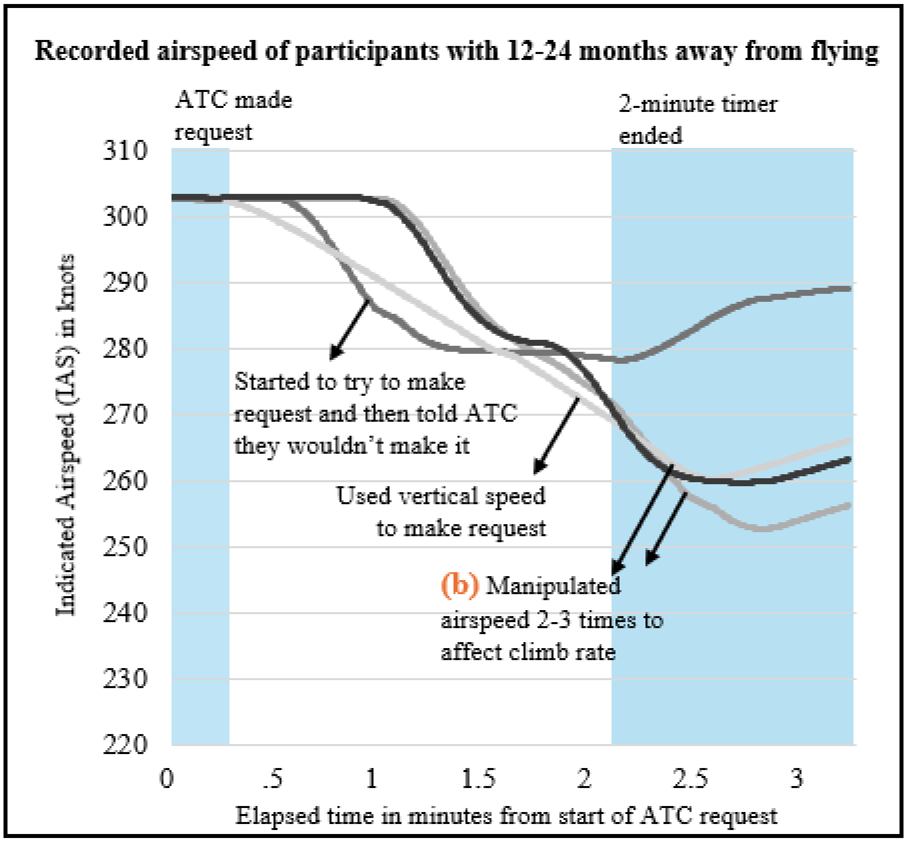
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 airspeed in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

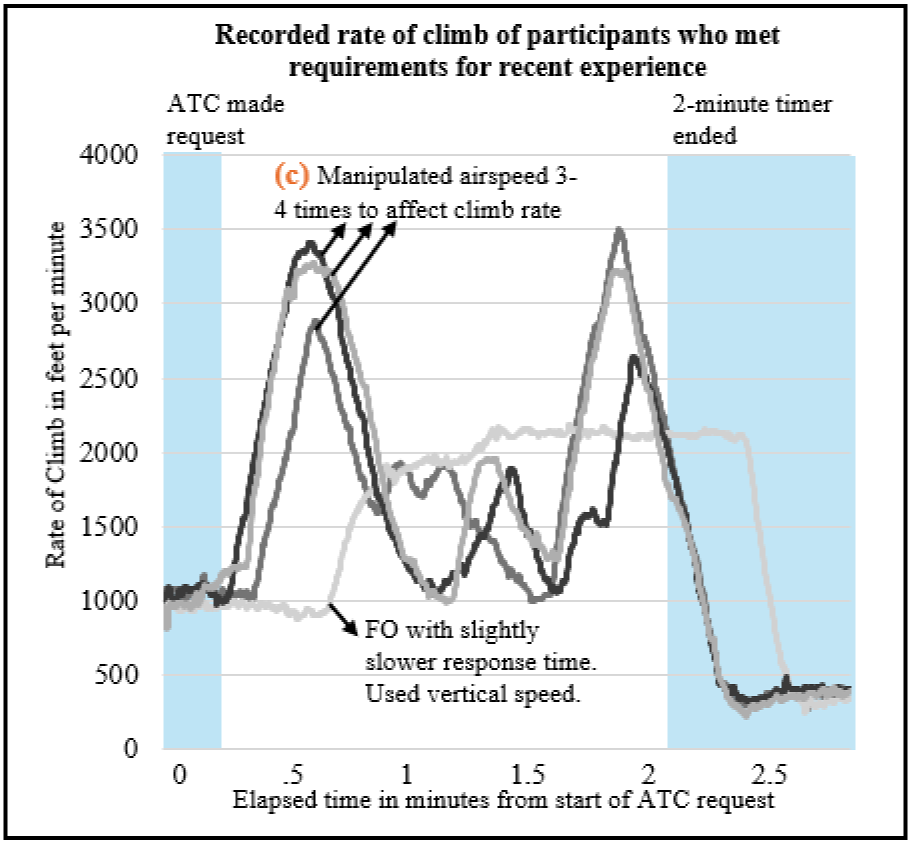
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 rate of climb in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

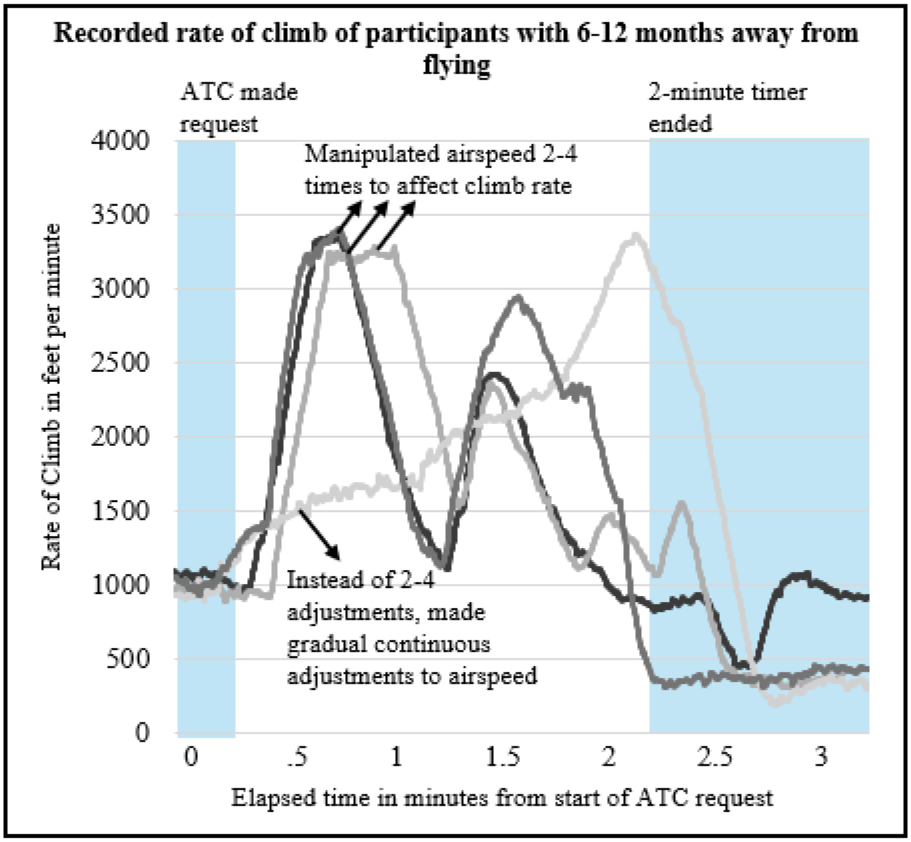
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 rate of climb in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

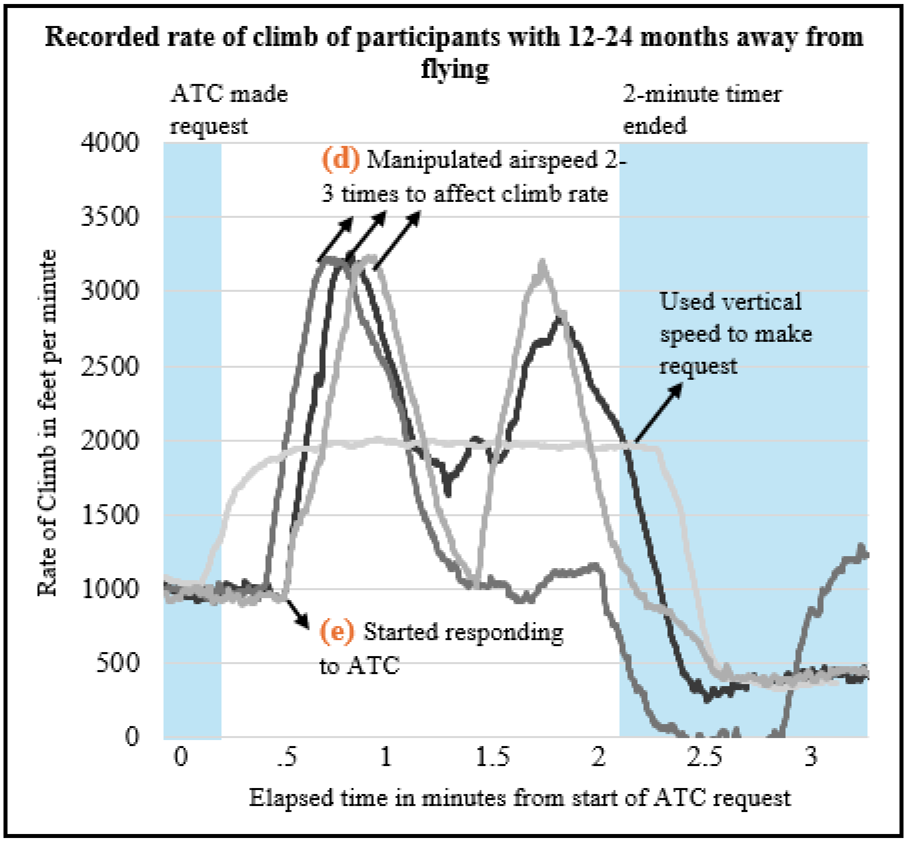
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 rate of climb in balancing tradeoffs between speed & vertical flightpath during climb at high altitude

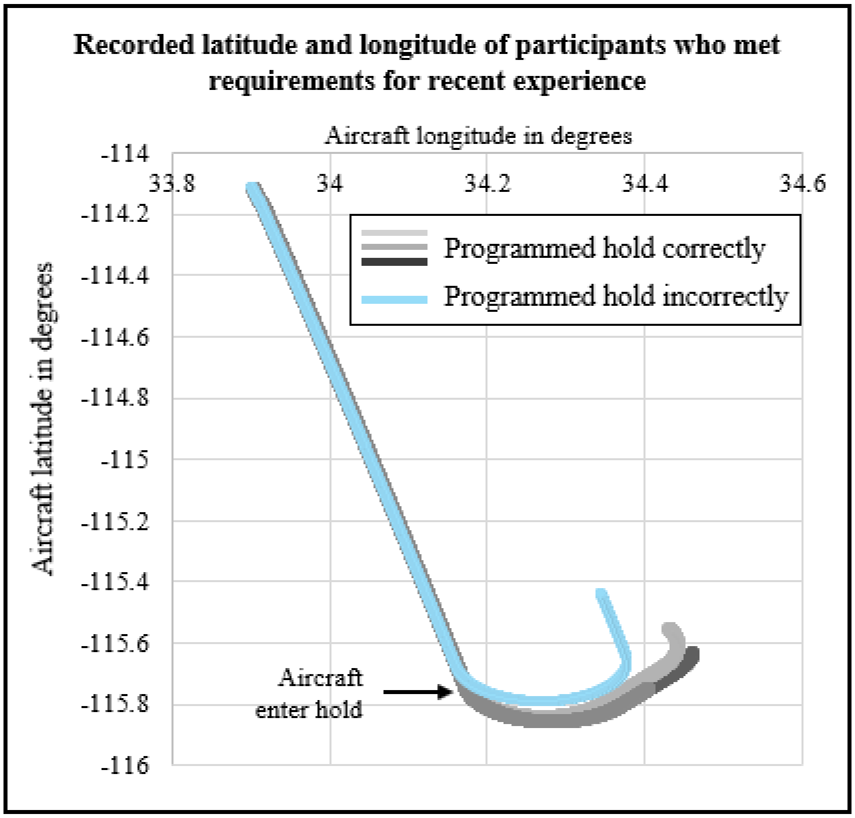
Cross-Sectional Study findings based on 12 participants flying the KEENS RNAV Departure from Phoenix in the latter climb FL280, ATC requested participants to climb to FL320 in two minutes or less.



25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 aircraft latitude and longitude when executing a hold in cruise.

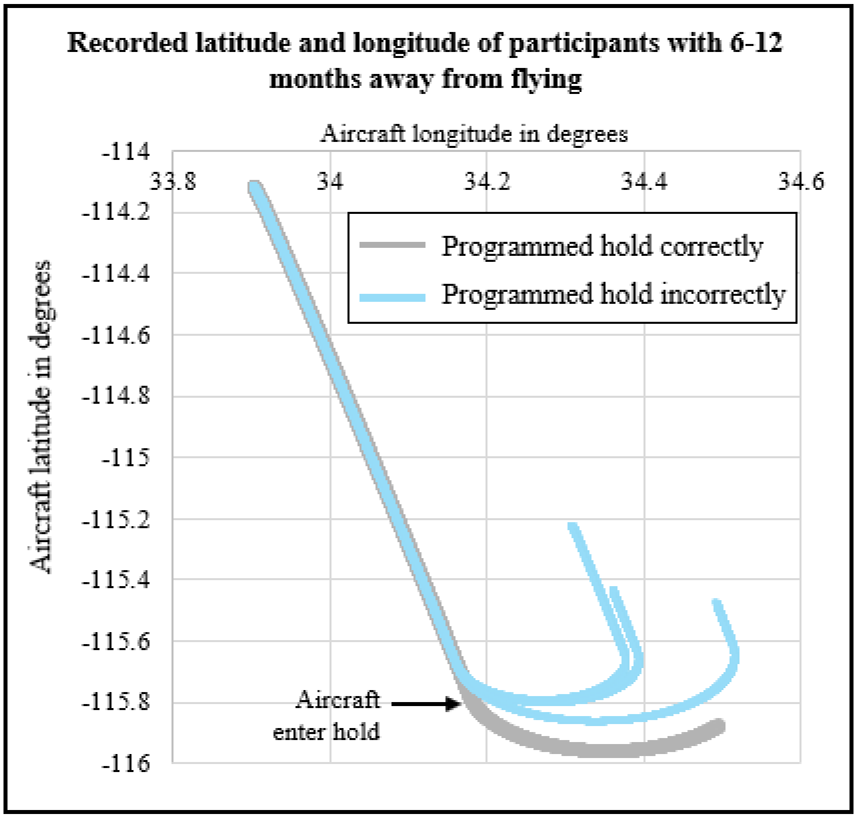
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 aircraft latitude and longitude when executing a hold in cruise.

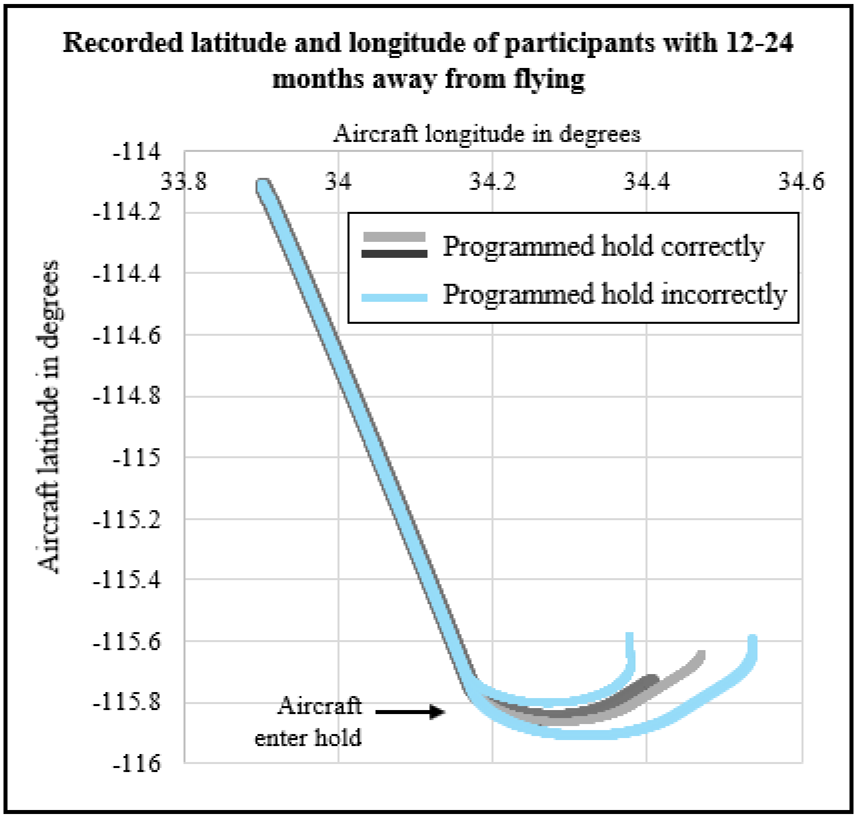
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 aircraft latitude and longitude when executing a hold in cruise.

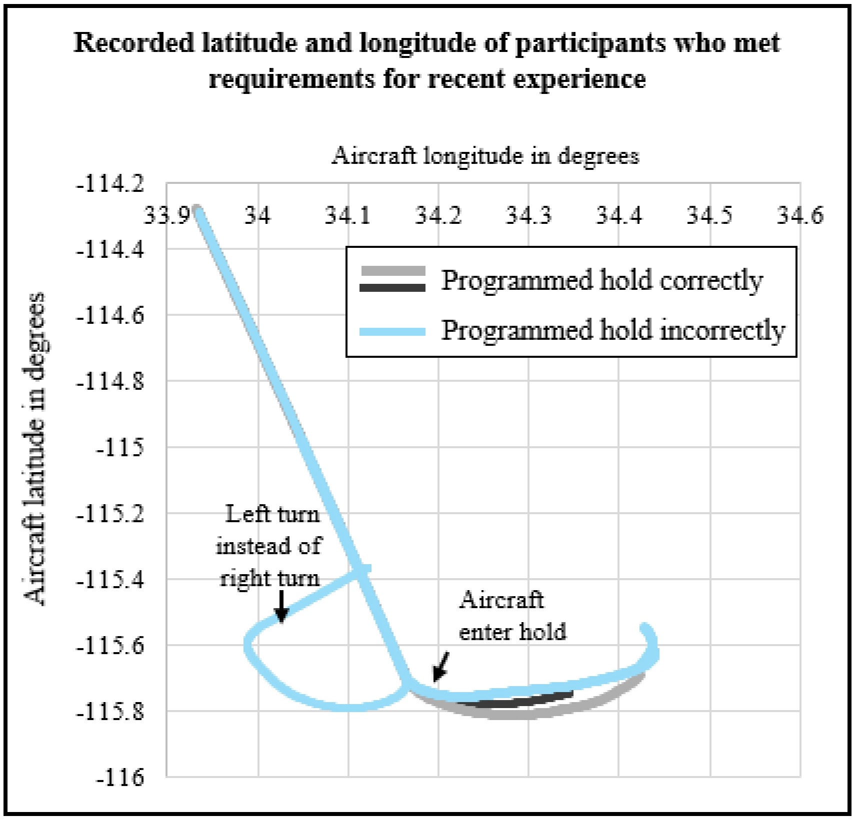
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 aircraft latitude and longitude when executing a hold in cruise.

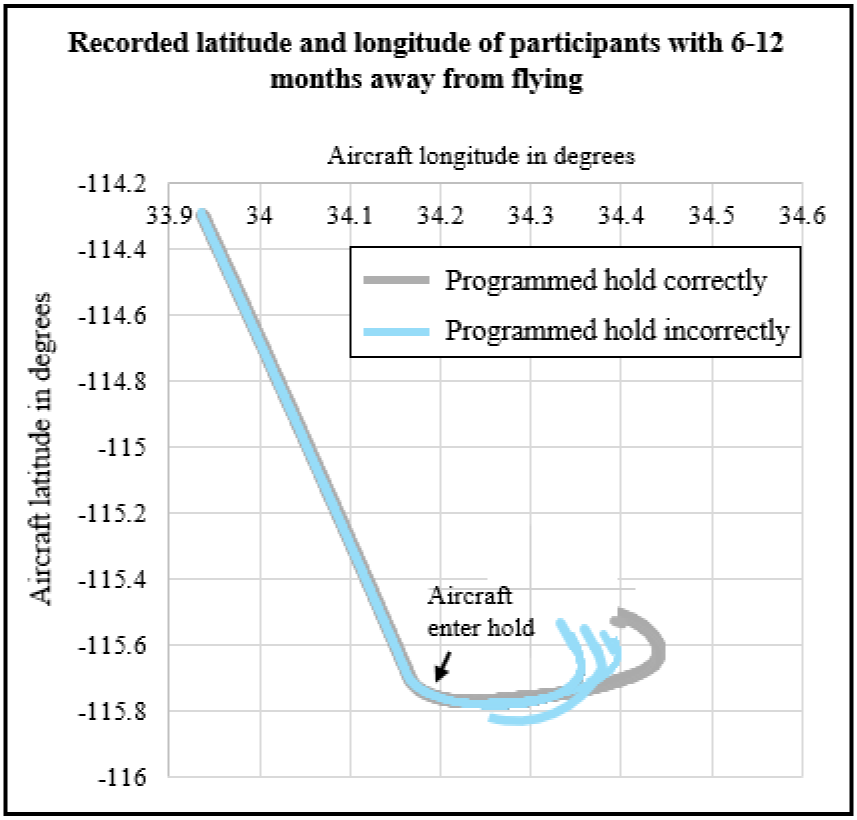
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of B737 participants who met requirements for recent experience on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 aircraft latitude and longitude when executing a hold in cruise.

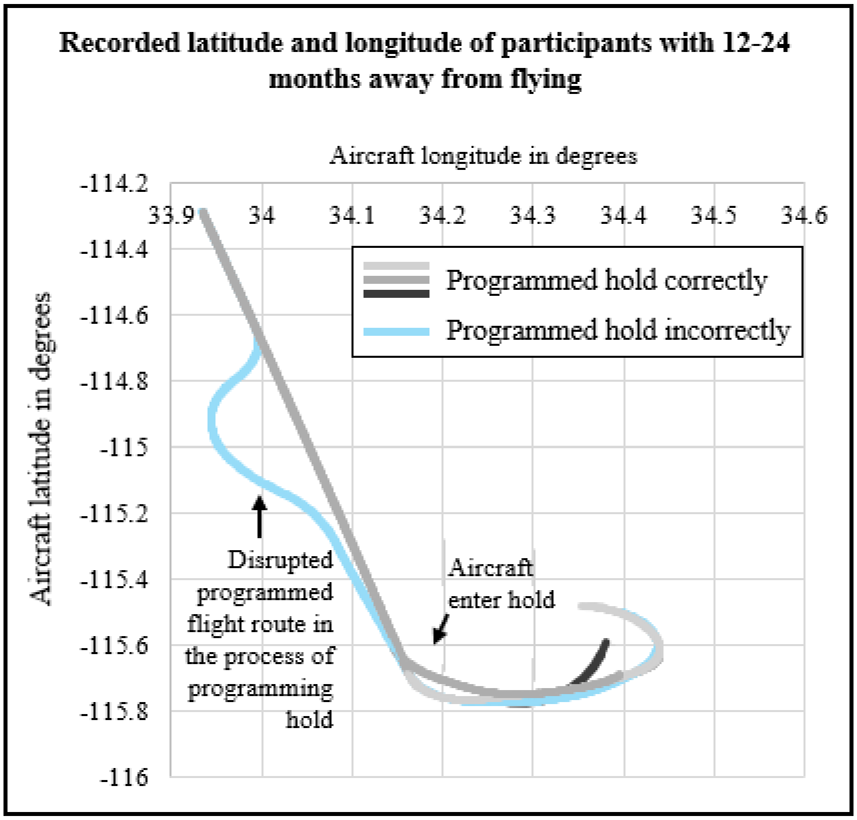
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of B737 participants with 6-12 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

B737 aircraft latitude and longitude when executing a hold in cruise.

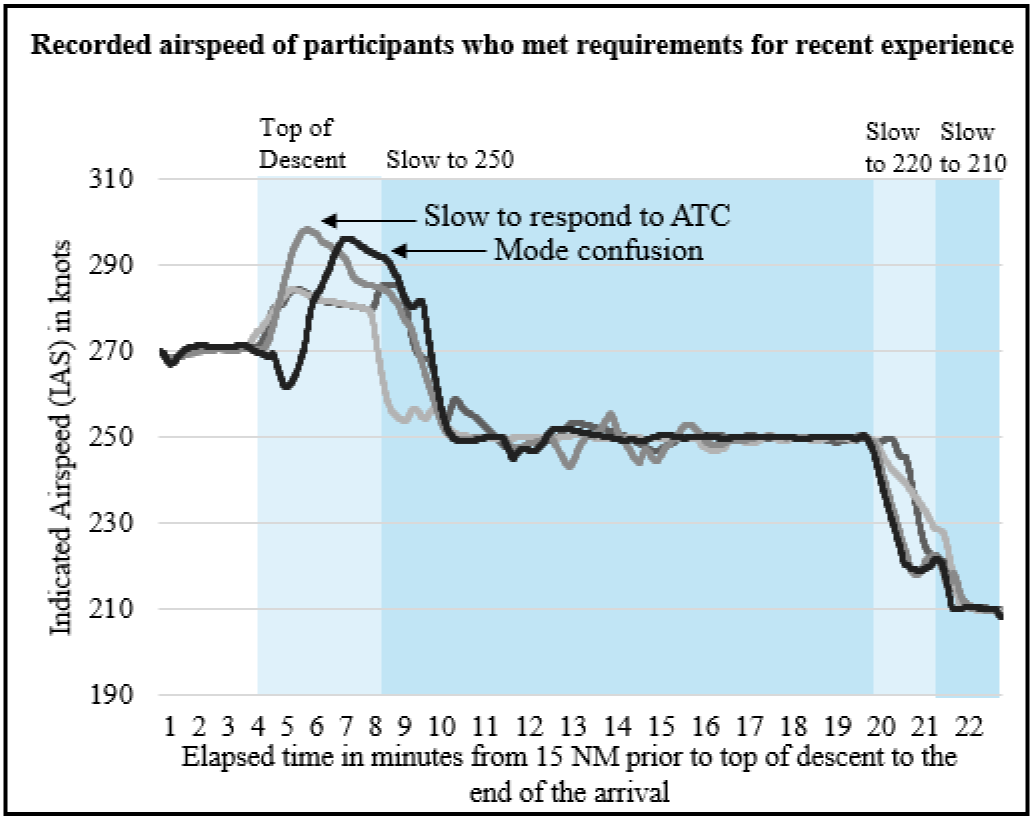
Cross-Sectional Study findings based on 12 participants programming and entering a hold at MDLER on the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of B737 participants with 12-24 months away from flying on the day of Cross-Sectional Study data collection. Percentage based on 12 participants.

A320 speed management during arrival

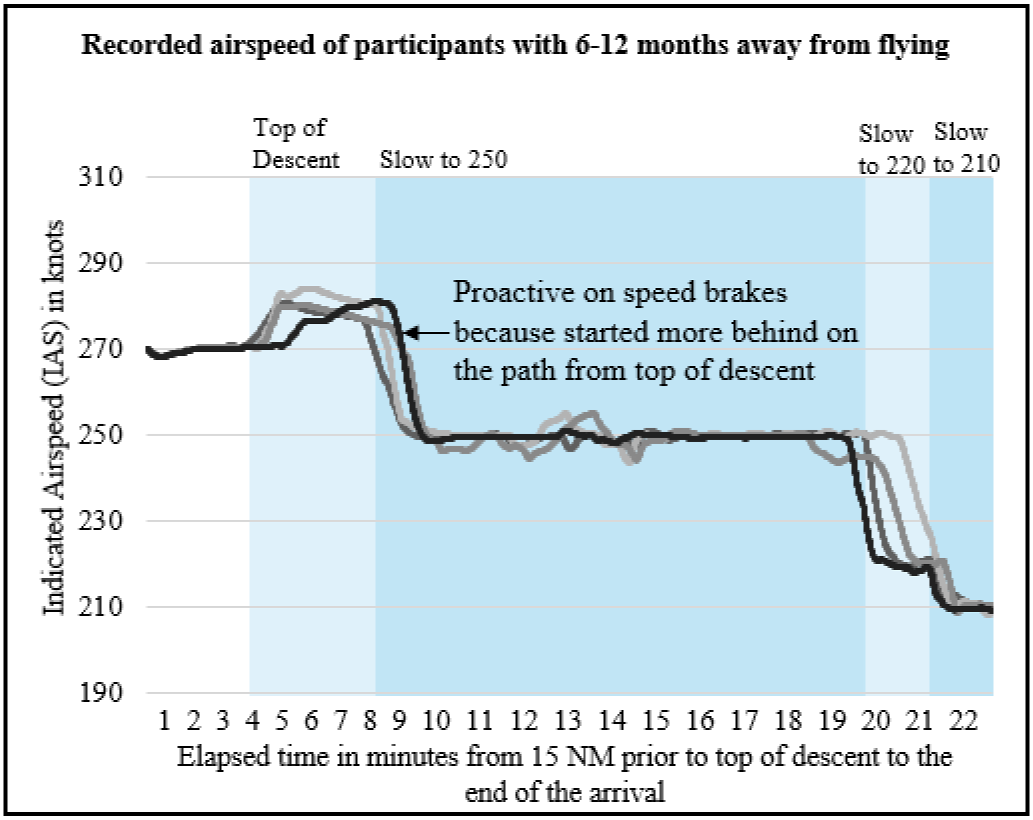
Cross-Sectional Study findings based on 24 participants flying the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants who met requirements for recent experience on the day of the Cross-Sectional Study data collection. Percentage is based on a total of 12 participants.

A320 speed management during arrival

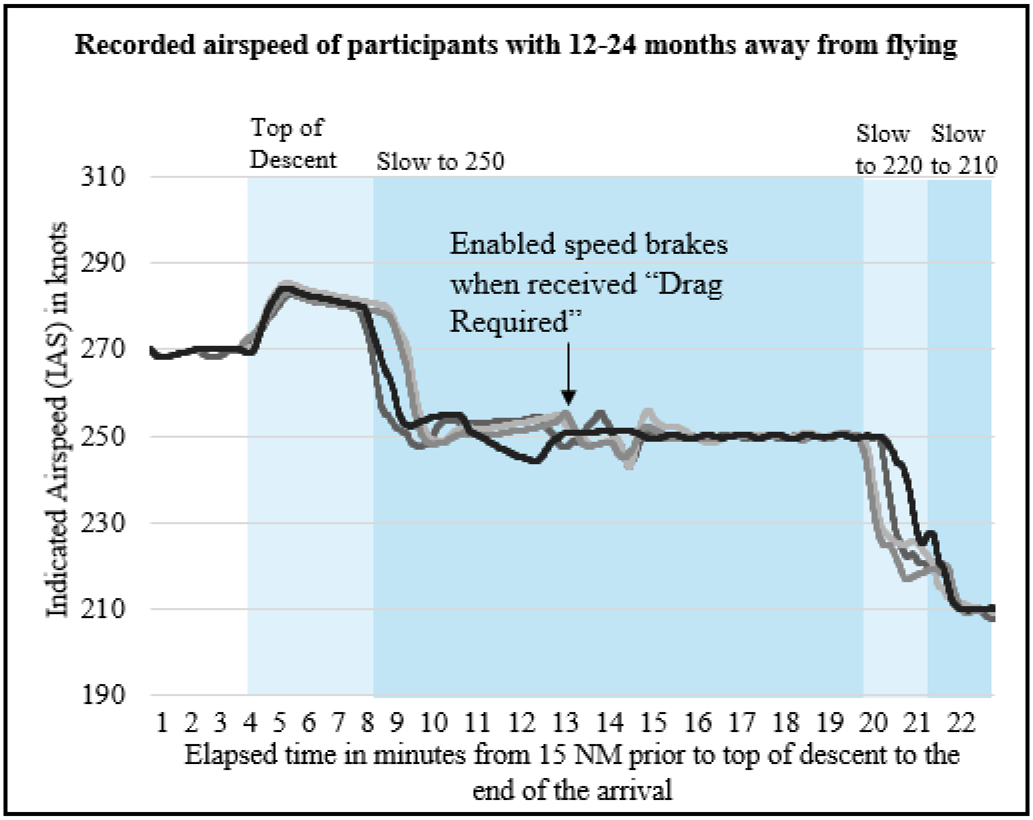
Cross-Sectional Study findings based on 24 participants flying the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants with 6-12 months away from flying on the day of the Cross-Sectional Study data collection. Percentage is based on a total of 12 participants.

A320 speed management during arrival

Cross-Sectional Study findings based on 24 participants flying the BRUEN2 RNAV Arrival to Los Angeles (KLAX)



25% (n = 4) of A320 participants with 12-24 months away from flying on the day of the Cross-Sectional Study data collection. Percentage is based on a total of 12 participants.

APPENDIX P – DATA MANAGEMENT PLAN

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