Flightcrew Human Factors in Message Complexity and Clearance Negotiation

Kim Cardosi, Ph.D.
Tracy Lennertz, Ph.D.

Final Report – August 2022

DOT-VNTSC-FAA-22-13

Prepared for:
US Department of Transportation
Federal Aviation Administration
800 Independence Avenue, SW
Washington, D.C. 20591

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
Volpe

Notice

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 2022	3. REPORT TYPE AND DATES COVERED Final report

4. TITLE AND SUBTITLE Flightcrew Human Factors in Message Complexity and Clearance Negotiation	5a. FUNDING NUMBERS FM03
6. AUTHOR(S) Kim Cardosi and Tracy Lennertz	5b. CONTRACT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) US Department of Transportation John A Volpe National Transportation Systems Center 55 Broadway Cambridge, MA 02142-1093	8. PERFORMING ORGANIZATION REPORT NUMBER DOT-VNTSC-FAA-22-13
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) US Department of Transportation Federal Aviation Administration 800 Independence Avenue, SW Washington, D.C. 20591	10. SPONSORING/MONITORING AGENCY REPORT
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Trajectory Based Operations (TBO) will support more efficient and user-preferred routes, requiring more complex communications between aircraft and the ground than today's operations. An understanding of the parameters of clearance negotiation, in current operations, will help to prevent these issues from occurring in near-term TBO and shape the development of procedures and best practices for future clearance negotiations. This research examined factors associated with clearance complexity and issues in clearance negotiation, with a focus on Controller Pilot Data Link Communications (CPDLC). To understand clearance complexity, this research reviewed relevant simulation literature, studies of flightcrew errors in entering and executing CPDLC clearances, pilot deviations documented in FAA Mandatory Occurrence Reports, reports submitted to the Aviation Safety Reporting System, and guidance for flightcrews on clearance negotiation. The results of this research will inform the refinement of guidance for pilots and controllers on clearance negotiation. The results also point to the need for continued human factors support for the development of clearance negotiation messages and procedures.

14. SUBJECT TERMS TBO, Flight Deck human factors, Trajectory Based Operations, Controller Pilot Data Link Communications, CPDLC, Data Comm, data link, clearance negotiation, clearance complexity	15. NUMBER OF PAGES 68
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yard	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
		NOTE: volumes greater than 1000 L shall be shown in m³		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	Kilopascals	0.145	poundforce per square inch	lbf/in²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Table of Contents

Acronyms and Abbreviations

AC	Aircraft
AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance- Broadcast
ANG-C1	FAA NextGen Human Factors Division
ARTCC	Air Route Traffic Control Center
ASAP	Aviation Safety Action Program
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATMG	Air Traffic Management Group
CDTI	Cockpit Display of Traffic Information
CDU	Control Display Unit
CPDLC	Controller Pilot Data Link Communications
DAG-TM	Distributed Air-Ground Traffic Management
DARP	Dynamic Airborne Route Planning
DCIT	Data Comm Implementation Team
DCL	Departure Clearance
DCPC	Direct Control Pilot Communications
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FL	Flight Level
FMC	Flight Management Computer
FMS	Flight Management System
FO	First Officer
GNE	Gross Navigational Error
GOLD	Global Operational Data Link (Manual)
HF	High Frequency
HITL	Human-in-the-Loop
HLA	High Level Airspace
ICAO	International Civil Aviation Organization
ILS	Instrument Landing System
LHD	Large-Height Deviations
MOR	Mandatory Occurrence Reports
NASA	National Aeronautics and Space Administration
NAS	National Airspace System
NAT	North Atlantic
NAT SPG	North Atlantic Systems Planning Group
NextGen	Next Generation Air Transportation System
NM	Nautical Mile

OCA	Oceanic Control Area
OEP	Oceanic Entry Point
OESB	Oceanic Error Safety Bulletin
PDC	Pre-Departure Clearance
PIC	Pilot-in-Command
RCL	Request for Clearance
QA	Quality Assurance
RTA	Required Time of Arrival
SATVOICE	Satellite Communication
SLOP	Strategic Lateral Offset Procedure
SID	Standard Instrument Departure
SPG	Special Planning Group
STAR	Standard Terminal Arrival
TOC	Transfer of Communications
TBO	Trajectory-Based Operations
UM	Uplink Message
TRACON	Terminal Radar Approach Control
VHF	Very High Frequency
WX	Weather

Preface

This report was prepared by the Transportation Human Factors Division of the Safety Management and Human Factors Technical Center at the U.S. Department of Transportation, John A. Volpe National Transportation Systems Center. This work was sponsored by the Federal Aviation Administration's (FAA) NextGen Human Factors Division (ANG-C1), with technical sponsorship from Aviation Safety (AVS), and Flight Standards (AFS). We thank Kevin Kelley, Dr. Kathy Abbott, Dr. Victor Quach, and Kevin Siragusa for technical guidance on this task and Kevin Kelley for substantial and helpful comments on an earlier draft.

Work on this report was funded under the FAA's NextGen Air/Ground Integration Human Factors Research Program.

For questions or comments, please contact Kim Cardosi, kim.cardosi@dot.gov.

Executive Summary

Trajectory Based Operations (TBO) will support more efficient and user-preferred routes. These operations will require more complex communications and exchange of data between aircraft and the ground than today's operations. The current work examined factors associated with clearance complexity and issues in clearance negotiation. An understanding of the parameters of clearance negotiation, in current operations, will help to prevent these issues from occurring in near-term TBO and shape the development of procedures and best practices for future clearance negotiations.

This research examines factors associated with message complexity and flightcrew errors made in clearance negotiation in pilot-controller communications, with a focus on text-based Controller Pilot Data Link Communications (CPDLC)—including a review of simulation literature, studies of flightcrew errors in entering and executing CPDLC clearances, pilot deviations documented in FAA Mandatory Occurrence Reports (MOR), and reports submitted to the Aviation Safety Reporting System (ASRS).

The complexity of CPDLC clearances was defined as the sum of factors that contribute to pilot errors associated with those clearances, with a focus on three aspects of complexity that can contribute to error: visual, cognitive, and technical. To successfully execute a CPDLC clearance, it must be read correctly, interpreted correctly, and then entered correctly into the Flight Management System (FMS).

Several human-in-the-loop simulation studies examined clearance negotiation with messages that were envisioned to be exchanged in a TBO environment. In most research reviewed, pilots and controllers had advanced tools to support the trajectory-based operations. Studies of flightcrew errors in entering and executing vertical and route clearances were reviewed for trends and causal factors in altitude deviations and lateral deviations in oceanic airspace.

Pilot deviations documented in over 4,000 oceanic and en route MORs were analyzed to understand errors in clearance negotiation and other factors that could affect pilots' adherence to a negotiated clearance. The analysis found several instances of pilots reading what they expected to see, going to an altitude that they had requested, and interpreting a question or statement from Air Traffic Control as an implied clearance. The most common error related to CPDLC clearances involved conditional clearances. The aspects of the clearances used in clearance negotiation associated with flightcrew errors were categorized according to visual and cognitive complexity (i.e., misreading a clearance, misinterpreting an informative message as a clearance, and misinterpreting a question as a clearance) and technical complexity (i.e., difficulty in programming or reviewing information in the FMS).

To gain insights into the causes of flightcrew errors associated with CPDLC clearances, reports submitted to the ASRS were reviewed. Eighty-five reports submitted between May 2016 and May 2021 that involved 14 CFR Part 121, 129, or 135 operations, where the result was an excursion from assigned altitude or clearance were analyzed. The causal factors of these errors, as identified from the pilots' perspectives, are discussed, including differences in revised messages, display issues, and message complexity.

Finally, guidance for flightcrews on clearance negotiation in the domestic en route and oceanic environments is presented. The Pilot Handbook U.S. Domestic Controller/Pilot Datalink Communication (CPDLC) Operations describes the clearance negotiations possible in today's en route environment (L3 Harris, 2021). Globally harmonized guidance on clearance negotiation in oceanic airspace is contained in the International Civil Aviation Organization (ICAO) Doc 10037, Global Operational Data Link (GOLD) Manual (ICAO, 2017).

The results of this research will inform the refinement of guidance for pilots and controllers on clearance negotiation and point to the need for continued human factors support for the development of clearance negotiation messages and procedures with the future (Baseline 2) message set.

1. Introduction

"With the increasing application of performance-based separations within the NAT [North Atlantic] Region, it is important that FANS 1/A (CPDLC/ADS-C) data link operations are functional so as to reduce impact and workload on both ATC and flight crews."
(NAT OPS Bulletin, NAT Data Link Special Emphasis Items,
ICAO North Atlantic System Planning Group, 2021, p. 2)

To increase both the safety and efficiency of the National Airspace System (NAS), the Federal Aviation Administration (FAA) is implementing the Next Generation Air Transportation System (NextGen). NextGen is a collection of technologies (FAA, 2018), that enable more precise and efficient flight paths for aircraft resulting in operational and environmental benefits (i.e., reduced emissions). This will require an increase in shared information between the air and ground and an increase in collaboration between air carrier operations and air traffic control and across air traffic control facilities. With NextGen, aircraft will participate in Trajectory-Based Operations (TBO) that include flight parameters for altitude, latitude, longitude, and time (FAA, 2017). This will require more complex communications and data exchange between pilots and controllers (Battiste et al., 2011). The primary means of communication of this complex information exchange on status, intent, and preferences will be datalink.

2. Purpose

The current work examined factors associated with clearance complexity and issues in clearance negotiation. The application of this understanding of the parameters of clearance negotiation in current operations will help to prevent these issues from adversely affecting operations in near-term TBO (including full TBO and Dynamic TBO) and will shape the development of procedures and best practices for future clearance negotiations.

This research examines the factors associated with message complexity and flightcrew errors made in clearance negotiation in pilot-controller communications, with a focus on CPDLC—including a review of past simulation data and pilot deviations from FAA Mandatory Occurrence Reports (MORs). The findings may inform future updates to Advisory Circular (AC) 91-70 (*Oceanic and Remote Continental Airspace Operations, Revision C*), AC 90-117 (*Data Link Communications*), the *Oceanic Error Safety Bulletin* (OESB), the International Civil Aviation Organization (ICAO) *Global Operational Data Link Manual* (Doc 10037), and the ICAO *North Atlantic Airspace and Operational Manual* (Doc 007).

3. Message Complexity

The issue of complexity in voice communications between pilots and controllers was examined by Morrow and Rodvold (1993). In a simulation study conducted with line pilots, they found that one message with four commands resulted in more incorrect readbacks, partial readbacks, and requests to repeat the message than did two messages with two commands each. Furthermore, the timing between the two short messages was also important. When the second message arrived within five seconds of the first short message, performance suffered.

Several studies of controller-pilot communications have examined the effect of message complexity on voice communications. Message complexity was first operationally defined for voice transmissions in Cardosi (1993) as the total number of elements contained in a single transmission. Each word or set of words that contained a new piece of information and was critical to the understanding of the message was considered an element. Each element could also be defined as an opportunity for error. For example, *"'*Air carrier 123, heading two five zero*'* was considered two elements ('heading' and '250'*)"* (p. 3).

Prinzo et al. (2009; Appendix A) constructed a *Guide to the Computation of Complexity: ATC Instruction/Clearance Aviation Topics*. This method was different from that used by Cardosi (1993) in that it deconstructs a clearance into "anchors, qualifiers, and excessive verbiage" (Prinzo et al., 2006, p.4). While not specifically defined, "anchors" are parts of the transmission that "make the communication element more precise in its interpretation" (Prinzo et al., 2006, p.3). The authors offer the example of "Contact Minneapolis Center one one eight point eight" and identifies the words "contact" and "point" as anchors (each counting a point toward the complexity score). The name of the facility and each digit after the initial (and invariant) 'one' each contribute another point to the complexity score for a total complexity score of six. Complexity points are added for "excessive verbiage" as "determined by comparing the speaker's utterance against the phraseology designated in FAA Order 7110.65" (Prinzo et al., 2009, p.4); examples of excessive words/phrases were "on, your, to, is, etc." (p. 19). For example, "Contact Cleveland Center *on* one three two point two five" would be scored higher in complexity than "Contact Cleveland Center one three two point two five". However, it is difficult to see how the addition of the word "on" in the context of a transfer of communication contributes to the complexity of a transmission, since it could be ignored without contributing to a communication error.

The most useful insights into the issue of complexity for verbal clearances resulted from Rantanen and Kokayeff (2002). This study defined a simple clearance as one that could be copied more accurately than a complex one. They conducted a part-task simulation in which pilots were asked to copy actual ATC clearances. Rantanen and Kokayeff (2002) found that the number of elements in a clearance alone was not sufficient to predict how accurately pilots would copy it. Clearances that contained elements pertaining only to navigation or altitude were deemed less complex than those that contained a mix of navigational, altitude, speed, and time information. A ranking of complexity based on the number of elements in the clearance and whether the clearance mixed different kinds of elements (e.g., navigational information with altitude or speed) and whether the clearance was congruent or not (i.e., the order of elements in the clearance corresponded to the progression of the flight) provided a more accurate prediction of performance than the number of clearance elements alone. The study concluded that other factors, such as expectations, need to be investigated. Although the definition of complexity used seems circular, **it is logical to define complexity in terms of factors that contribute to error**. To this end, the number of elements, whether the elements in the clearance are presented in the order that they should be executed, and whether all the elements pertain to a vertical or horizontal clearance, or if they are mixed in the transmission, would be components of complexity in the verbal or CPDLC domain.

The effect of message length on performance has only been examined for CPDLC clearances by McGann, Lozito, and Corker (1992). The purpose of this simulation study was to explore four different formats for the presentation of Terminal Radar Approach Control (TRACON) clearances in a visual format on a dedicated display – none of the formats were similar to the displays used to present Future Air Navigation System (FANS) messages. Messages contained two to five elements (pieces of information). The pilots' task was to either recall the clearance (via a verbal readback) or determine whether a specific element (e.g., altitude) was the same or different in the clearance presented than in the previous clearance (with a brief blank screen presented in between the two). While no differences on pilot response time or accuracy were found as a function of the different formats used, there was a significant difference in response accuracy as a function of the number of elements. Accuracy in both tasks decreased as the number of elements increased. Performance was significantly more accurate with two elements than with three, and significantly more accurate with three elements than with four. In fact, the only difference that was not significant was the difference between four and five elements where performance was equally poor. Interestingly, this parallels a study of readback errors from voice clearances in the TRACON environment in which clearances that contained four or more pieces of information made up only 26% of the readbacks in the analysis but accounted for 51% of the readback errors found in the study (Cardosi et al., 1996).

To execute a CPDLC clearance successfully, it must be read correctly, interpreted correctly, and then entered correctly into the Flight Management System (FMS). Thus, it is helpful to consider three aspects of complexity that can contribute to error: visual, cognitive, and technical.

3.1 Visual and Cognitive Complexity

Amount of information. The complexity of a transmission, whether via voice or CPDLC, increases with the amount of information it contains. Too much information can overload short-term memory. Short-term or "working" memory stores the information that we use immediately in a task, such as remembering a phone number just long enough to dial it. When this storage capacity is overloaded, some of the information (usually the information presented in the middle) will be lost. With CPDLC, the amount of information contained in a single transmission is correlated with the *number of pages* on which the clearance is displayed on the flight deck. The number of elements in a clearance has also been identified by pilots as adding to the complexity of the clearance (Smith et al., 2001).

Simplicity and intuitiveness of the clearance. Misinterpretation of clearances can be due to reading what the pilot expects to see rather than what is presented. With a revised clearance, pilots may miss the difference between the new clearance and the one they received previously, particularly if the difference is small. In a response to a request, a pilot may 'see' the altitude they requested in the clearance, rather than the altitude they were issued. However, errors are not always due to misreading a clearance. Pilots have misinterpreted transmissions from a controller that were intended only to convey information as a clearance. A pilot must be able to recognize a clearance as a clearance and understand the intent of each component. Then, the pilot must remember to execute the action when appropriate. Conditional clearances that require a pilot to delay an action until a future time increase memory load and the pilot may forget to execute the clearance. Alternatively, the condition may be unintentionally ignored, resulting in the pilot executing the clearance too early. Executing a clearance too early or too late can result in a loss of standard separation with other aircraft (See Kraft, 2014).

3.2 Technical Complexity

Ease of entering the clearance into the FMS and reviewing the entered clearance. Even if a pilot accurately perceives and understands a clearance, it can be a challenge to program it into the FMS and then to review the loaded clearance and determine if additional components need to be manually entered. Clearances that can be loaded (e.g., with a "LOAD" prompt) in the FMS can reduce errors associated with manual data entry but can add complexity when only some of the portions of the clearance are loaded. This means that the pilot must discern what portions of the clearance are loaded into the FMS and which need to be manually entered. The categories of visual, cognitive, and technical complexity are not mutually exclusive in that one type of complexity can lead to another. Furthermore, pilots' expectations would play a role in each of these aspects of complexity (e.g., seeing what one expects to see, interpreting a question as a desired clearance, and expecting that an entire clearance has been entered into the FMS, when in fact it has not). The categories provide a framework for recognizing/discussing the multi-dimensional aspect of complexity of CPDLC clearances and working toward error mitigation strategies.

3.3 Pilot Insights on Complexity

The best insights about the specific aspects of a CPDLC clearance that contribute to complexity come from a survey of 318 Boeing 747-400 pilots (from three air carriers) with experience using FANS on South Pacific routes (Smith et al., 2001). The results are organized in the framework presented above.

3.3.1 Visual and Cognitive Complexity

Thirty-one percent (91/295) of the pilots said the presentation of FANS clearances on the ATC UPLINK[1] page was "not always adequate." The most common reason identified (by 23% of these pilots) for describing a presentation as inadequate was that uplink message required two or more pages. Sixty-two of the 305 pilots (20%) who received "multiple element" clearances reported overlooking part of the clearance on at least one occasion. One pilot stated that "clearances should be able to be read as complete sentences" (Smith et al., 2001, p. 6), which is more difficult when it is conveyed across more

[1] Per the *Global Operational Data Link (GOLD) Manual* (ICAO Doc 10037, 2017), uplink messages are those sent from a ground system; downlink messages are those sent from an aircraft.

than one page.

While 31% of the respondents said that the presentation was “not always adequate”, some of the reasons cited had nothing to do with message length. Instead, they cited use of non-standard phraseology or free text (17/91 or 18%), message layout (14%), and conditional clearances (9%) – each of which can add complexity to the interpretation and memory for the execution of clearance. In fact, 64 of the 304 pilots (21%) who had received conditional clearances reported misunderstanding a conditional clearance at least once.

The use of latitude and longitude coordinates instead of named waypoints can add to the complexity of interpreting a clearance, especially if it needs to be manually entered into the FMS. Twelve of the 128 pilots (9.5%) who received uplink clearances that included latitude and longitude coordinates reported that on at least one occasion those coordinates were misunderstood.

Some pilots stated that CPDLC clearances can be cryptic in “incomplete text” and wished that they were presented more like the clearances they hear over the radio. Other pilots stated that including “REQUEST” on the ATC UPLINK page, displaying ATC’s response to the pilot’s request, was confusing, even “bewildering” as it could lead the pilot to think that an ATC request was being displayed, when in fact it is the controller’s response to the pilot’s request.

Most pilots (62%) reported switching from data link to voice (either High Frequency [HF] radio or SATVOICE) to resolve a question on the clearance. Thirty-six percent of the pilots reported rejecting a clearance on at least one flight because its intent was unclear.

The most important finding pertaining to clearance negotiation was that 52% of the pilots reported having been “uncertain on at least one occasion whether an ATC uplink was a response to a downlinked request” and stated that, “in some cases, the reply seemed unrelated to their request, e.g., REQUEST L10 [Nautical Mile] NM DUE WX. Response: CLEAR R10NM.’” While the controller used free text to respond to this request in this example, “Even when the appropriate formatted messages were used… there was some confusion” (p. 5).

Finally, 74% of the pilots wanted feedback that the downlink message was seen by a controller. This would be an important component to a clearance negotiation. While 20% of the pilots stated that the ATC response time for routine requests was unacceptably long, our conclusion should be that the ATC response times seen in the FANS/South Pacific environment over 20 years ago may not be considered acceptable by pilots in a clearance negotiation. The same caveat applies to the finding that 33% of the pilots rated response time for urgent requests (e.g., weather deviations) unacceptable with one adding that they, “Frequently must use emergency authority to deviate” (Smith et al., 2001, p.7).

3.3.2 Technical Complexity

Several types of FANS uplink clearances (e.g., route amendments) include elements that can be loaded directly into the aircraft’s FMS with a LOAD prompt. This greatly reduces the chance of an error due to data entry (particularly with latitude and longitude coordinates). The number and type of clearances that are loadable vary from flight deck to flight deck.

Ninety of the 295 (30%) pilots in the Smith et al. (2001) study reported receiving loadable messages from ATC. These included 44 "DARP" (Dynamic Airborne Route Planning) route amendments, 26 RTA (required time of arrival), 24 "Direct-To," 22 route offsets, and nine "other" clearances. Thirty-two of the 90 pilots (36%) rated "Predicting what part of the uplink message will load" as moderately difficult or difficult (four or five on a 5-point scale). Twenty-four percent rated "Knowing where to review the loaded changes" as moderately difficult or difficult. While only 13% rated "Detecting the LOAD> prompt" as "moderately difficult" 22% reported overlooking the LOAD prompt on the ATC UPLINK page at least once

3.3.3 A Model of Pilot-Controller Miscommunications

Skaltas, Rakas and Karlaftis (2013) purport to have developed a "probabilistic model with high predictive accuracy" of miscommunications between pilots and air traffic controllers. To construct this model, the authors examined 7,965 transcribed controller-pilot messages from 42 thirty-minute voice communication recordings from 33 sectors in five air route traffic control centers (ARTCCs) of US airspace which they note accounts for about 8% of the en route messages exchanged during a typical hour in US airspace. The analysis of these recordings revealed 382 miscommunications. These communication errors were classified as due to "pilot mishearing" (28%), "pilot not responding" (20%), "controller mishearing" (15%), and "controller not responding" (11%). The majority of the remaining miscommunications involved messages sent by controllers to aircraft that either had not yet checked-in with the sector or had already been handed off. Twelve factors were identified that affect the probability of a voice communication error, with different factors influencing the probability of an error made by pilots and those made by controllers. The most important factors affecting communications were length and context of the message, entering of an aircraft into a sector, transfer of communication, and radio frequency congestion. While the complexity of the message transmitted was not considered, it is likely correlated with message duration. Furthermore, the errors found with transfer of communication are not surprising, given the longstanding finding that pilots make more readback errors with radio frequencies than any other type of information (e.g., Cardosi et al., 1996). The study also showed that lengthy messages increased the potential for error. The effect of message length in readback of en route messages was also not new (Cardosi et al., 1996).

The authors theoretically relate the same factors used to assess voice communications to the probability of a miscommunication via CPDLC. However, this application was not examined with any CPDLC transmissions. Indeed, the authors note, "Although we intuitively postulated that the listed parameters are statistically significant, we were able to quantify such results only by developing a comprehensive methodology" (p.51). The notion that an increase in frequency congestion could lead to an increase in delayed responses to CPDLC messages seems sound, but any factor that increases pilot workload would likely lead to a delayed response to a CPDLC message. A model that predicts communication errors with CPDLC messages would be useful. However, a model based solely on voice communications that does not consider the different nature of CPDLC clearances is not useful and would be misleading.

4. Review of Relevant Simulation Literature

The concept of message complexity is critical to understanding clearance negotiation between pilot and controllers in the TBO environment. Several human-in-the-loop (HITL) simulation studies examined clearance negotiation with messages that they envision being exchanged in a TBO environment. Some of the simulation research compared voice and data link performance and the findings echo the operational experience of pilots as described by Smith et al. (2001).

4.1 Voice vs. Data Link

A number of simulation studies compared voice with data link performance for clearance negotiation (Battiste et al., 2011; Brandt et al., 2011; Johnson et al., 2011)—with similar results. Johnson et al. (2011) examined pilot and controller performance with voice and two data link implementations: Aircraft Communications Addressing and Reporting System (ACARS) and FANS 1/A. As in real operations, ACARS required the use of free text on the flight deck; FANS 1/A was integrated in the FMS. Compared to voice, both ACARS and FANS 1/A clearance requests from the pilot to the controller were associated with a slower response time and an overall longer duration of communications. In this 2011 simulation study, pilots preferred voice to data link, particularly the non-integrated ACARS implementation (Johnson et al., 2011) for clearance negotiation (e.g., a re-route due to weather).

Brandt et al. (2011) similarly observed a preference for voice compared to data link in a desktop simulation study when pilots and controllers negotiated weather re-routes; in general, pilots preferred voice to data link. The main reason was that data link clearances were associated with a slower response time from controllers. Related research examined communication via voice and data link from a controller perspective (Battiste et al., 2011); again, voice was preferred to data link. As noted by Battiste et al. (2011)—and is likely the case with most of the research reviewed—participants were more familiar (and thus, more comfortable) with voice compared to data link.

Taken together, this research demonstrates that pilot-controller communications via data link require more time than via voice, when the voice communications are direct from the controller to pilot. It is important to note that this research does not speak to the relative time required of data link compared to third-party voice (in which the communications are relayed by an aeronautical radio station). This is an important distinction that mirrors current differences in communication capabilities in the aviation environments. In oceanic airspace, pilot-controller communications are relayed via data link, an aeronautical radio station, or satellite voice. In domestic airspace, pilots and controllers communicate directly with each other via Very High Frequency [VHF] voice, and CPDLC, as the capability for CPDLC is implemented. The time required for transmission of the same message via each of these communication media has not been systematically studied. While it is logical to expect that the time between a request for a change in altitude, for example, and the receipt of the clearance for the requested altitude would take longer via data link than direct voice, there are advantages to sending such requests via data link especially in the oceanic environment where responses from ATC are likely to be faster via CPDLC due to the facts that voice transmissions need to go through a third party and that the ground system in the US automatically conflict probes the requested altitude.

4.2 Simulation Studies of TBO Clearance Negotiation

Clearance negotiation is a critical component in the realization of expected NextGen benefits of increased route flexibility, airspace and flight efficiency, and the accommodation of user preferences (Green et al., 2000; see also Prevôt et al., 2003; 2004). In an early set of studies, NASA explored trajectory negotiation with Distributed Air-Ground Traffic Management (DAG-TM). With this concept, some air traffic responsibilities are "distributed" between the pilot and controller. Negotiation is required when there are constraints (e.g., on traffic flow, on the need to re-route around weather) or parameters that can impact the preferred route. In the DAG-TM concept, clearance negotiation is aided by increased information sharing and enabling technologies—such as ADS-B, a Cockpit Display of Traffic Information (CDTI), and CPDLC. Together, these tools can help the flightcrew negotiate about the flight trajectory. Having this shared information may increase the likelihood that ATC can accommodate the request (Green et al., 2000).

Much of the research on this early TBO concept focuses on the functionality of the tools that will need to be available to the controller and assumes equipage on the flight deck that is not currently available (e.g., Prevôt et al., 2003; 2004). Increased information sharing between the air and ground, resulting in less frequent, strategic clearances, is expected to reduce workload for controllers (e.g., Weber & Crűck, 2007). Many of the flight deck tools included in the DAG-TM and related concepts (e.g., Green et al., 2000; Prevôt et al., 2003; 2004) are not available on the flight deck; moreover, in real operations, equipage varies across flight decks (e.g., in the level of integration between the message set and the FMS; the display of ADS-B information). Currently, the level of automation that exists on the flight deck to support the flightcrew in responding to clearances (including conditional clearances) varies considerably from flight deck to flight deck. This variability was not included in most of the simulation and concept development research reviewed. Given this, it is likely that the need for negotiation between the flightcrew and ATC is more frequent than is reflected in this initial concept description. The complexity of the messages exchanged between pilots and controllers is likely also underestimated.

Smith et al. (2004) examined pilot and controller clearance negotiation as defined by the DAG-TM concept in two HITL simulation studies. The first study varied the tools available for decision making on the flight deck and on the ground. The study found an increase in efficiency—as defined by spacing between aircraft—with both automation in the air (i.e., a CDTI with conflict detection and resolution and Required Time of Arrival [RTA] tools) and on the ground. Pilots also reported a small increase in workload when using these decision support tools on the flight deck, compared to when the tools were not available.

The second study (also reported in Lee et al., 2004), varied how pilots made requests to the controller (i.e., via voice or data link) and the capabilities available to the pilot and controllers to assist in decision making. In the baseline condition, CPDLC was only for Transfer of Communications (TOC), in other conditions, 1) CPDLC was used for uplink messages only, 2) CPDLC was used for *both* uplinks and downlinks, and 3) uplinks and downlinks with a conflict detection and resolution *tool on the flight deck*. Pilots were instructed to initiate scripted negotiations with controllers; the focus was mainly on controller performance. Voice was used for negotiation in the baseline and uplink message only conditions; with downlink messages, pilots could initiate negotiations via CPDLC. In all conditions, when a request was rejected, the controller contacted the flightcrew by voice. The results demonstrate that pilot-controller negotiation is "operationally feasible" (Smith et al., 2004, p.8); 68% of the requests were approved on the first request, and this occurred most often when the notional conflict detection and resolution tool designed for the study was available on the flight deck (Lee et al., 2004; Smith et al., 2003).

Two HITL simulations conducted by Mueller and Lozito (2008) focused on flightcrew performance. Specifically, this research examined how some of the parameters of clearance negotiation affect flightcrew performance. The first study sought to determine the appropriate flightcrew procedure for the receipt of a data link message—predictable procedures can help to standardize performance/response time across flightcrews.

Although some aspects of the recommended procedure have changed since this study—flightcrews are no longer instructed to print out the message on the flight deck—this "print and silent read" procedure was used in the second simulation study by Mueller and Lozito (2008). This study varied the number of message elements in a clearance (a parameter of message complexity), and level of detail that was provided in association with a clearance—and examined the effects on flightcrew performance. Specifically, clearances (vertical and horizontal) included either single or multiple elements. Clearances also varied on whether they were preceded by an "expect" message or accompanied with a "due to" reason. Flightcrews were instructed to negotiate with the controller regarding any clearance that they considered to be "inefficient, impossible or impractical" (p. 6). Examples included: "an altitude clearance that could not be achieved due to the weight of the aircraft; an unachievable climb or descent rate; weather cells present on the route of flight or in a revised trajectory; and large heading changes that caused very inefficient flight plans" (Mueller & Lozito, 2008, p.6).

Results indicated that crews took longer to provide a "WILCO" response to horizontal compared to vertical clearances, as horizontal clearances are likely to be more complex; the authors note this increased response time may be due to the number of steps needed to implement a horizontal compared to a vertical clearance on the flight deck, and that vertical clearances may be perceived as "more time-critical" (Mueller & Lozito, 2008, p. 10). Whether one or two message elements were included in the clearance, it did not appear to impact response time for horizontal messages, however, the response time for single-element vertical messages tended to be faster than multiple element ones.

Mueller and Lozito (2008) observed that the inclusion of a "due to" reason or an "expect" message did not significantly change flightcrew response time to a clearance (both vertical and horizontal). "Expect" messages preceded the receipt of a clearance on the flight deck, and yielded a small, but not significant decrease in response time to the clearance. Flightcrews considered "any message coming from ATC to be important" (p. 12)—and consequently the inclusion of a "due to" reason did not impact response time (Mueller & Lozito, 2008). Results also indicated that the flightcrews were most likely to negotiate (in order of frequency) altitude requests, clearances that they were unable to WILCO, and weather deviations; they were least likely to negotiate a heading. In this study, flightcrew responses to negotiated clearances tended to take slightly more time than non-negotiated clearances; however, this increase in response time did not appear to be operationally significant—nearly all clearances were responded to within two minutes. While other research has shown a preference for voice over data link communications, in Mueller and Lozito (2008), fewer than 5% of the flightcrews switched from data link to voice to negotiate about a clearance.

In most of these studies, pilots and controllers had advanced tools to support trajectory-based operations (e.g., a CDTI on the flight deck—a visual display of traffic, with conflict detection and suggested resolutions) and communication occurred in optimal, simulated conditions. Aircraft were typically equipped with technology to downlink their projected trajectory to the ground and the ground could uplink a route clearance to the aircraft (cf. Green et al., 2000; Weber & Crűck, 2007). Many of these capabilities are assumed for Dynamic TBO, which is described as "[using] advanced aircraft and ground automation to enable flight specific time-based solutions for reroutes and aircraft sequencing and advanced aircraft-based pairwise trajectory solutions. Information will be integrated and shared to further improve NAS operations" (FAA, *NextGen's Path to TBO*, 2018).

In real operations, the information exchanged between parties may be more complex compared to the information that was communicated in the HITL simulations. Additionally, in the simulation studies, the air/ground automation performed flawlessly, the procedures were clear, and no anomalous events were introduced. As always, we must assume the performance seen in simulation studies to be the "best case".

5. Studies of Flightcrew Errors in Entering and Executing CPLDC Clearances

5.1 ICAO North Atlantic Airspace and Operational Manual

The *ICAO North Atlantic Airspace and Operational Manual* (Doc 007, 2022) describes the most common flightcrew errors that result in lateral navigation errors and altitude deviations.

Lateral navigation errors. The most common cause of lateral navigation errors identified was a revised clearance. Specifically, "having already inserted the filed flight plan route coordinates into the navigation computers, the flight crew have been re-cleared by ATC, or have asked for and obtained a re-clearance, but have then omitted to re-program the navigation system(s), amend the Master Document or update the plotting chart accordingly" (p.106). The fact that most of the errors were linked to a revised clearance is neither surprising, nor particularly helpful. Each revision presents an opportunity for error in clearance entry or execution. More helpful is the finding that it was "common" (although not quantified) for a mistake of one degree of latitude to be made in inserting a waypoint. "There seems to be a greater tendency for this error to be made when a track, after passing through the same latitude at several waypoints (e.g. 57°N 50°W, 57°N 40°W, 57°N 30°W) then changes by one degree of latitude (e.g. 56°N 20°W)" (p.106). The report also notes that, "In some cases, the flight crew has heard not what was said, but what they were expecting to hear." (p.106).

Altitude deviations. Some of the causal factors for flightcrew errors that result in altitude deviations, for example, 'executing a climb without a clearance', are not sufficiently detailed to point to error mitigation strategies. Others, such as not following the correct procedure for a weather deviation, are not germane to clearance negotiation. 'Not climbing or descending as cleared', however, was noted as 'often associated with conditional clearances', but this was neither quantified nor explored in detail.

Other than misinterpreting a conditional clearance, the only other causal factor for altitude deviations associated with CPDLC messages was misinterpreting an ATC response to a request as a clearance. The manual specifically states, "acknowledgements of requests do not constitute approval".

5.2 Studies of Conditional Clearances

The ICAO *North Atlantic Operations Manual* (2022) noted that Large Height Deviations were 'often associated with conditional clearances'. The ICAO *North Atlantic Operations Bulletin* (2017-002_Revision 04), the Oceanic Errors Safety Bulletin, also notes that "Conditional clearances, especially climb clearances with delayed execution, are associated with a disproportionately high error rate" (ICAO, 2021, p.4). Neither document, however, quantified the rate.

Conditional clearances, specifically the use of "AT [time/position] CLIMB/DESCEND TO [level]" and "CLIMB/DESCEND TO REACH [level] BY [time/position]", were identified as a risk factor in altitude deviations in 2010 by both Portugal (NAT ATMG/35 WP 22) and the United Kingdom (NAT ATMG/35 WP 18). This risk was explored in more detail by Kraft (2014) who quantified the relation between conditional clearances and Large-Height Deviations (LHDs) in the NAT Region. LHDs are defined by ICAO as a deviation of 90 meters (300 feet) or more from the cleared flight level. Many of the reports of this type of error specify that the clearance was issued after a pilot request for a specific altitude. However, not all reports specify whether there was a pilot request.

The first study on the relation between altitude deviations and conditional clearances in the NAT found that "CLIMB TO REACH [level] BY [time]" was the most commonly used conditional clearance in New York Oceanic Control Area (OCA) from 2007 to 2012 (Kraft, 2014). However, it was the use of "AT [time] CLIMB TO [level]" combined with the "CLIMB TO REACH [level] BY [time]" was more likely to result in an altitude deviation than the use of "CLIMB TO REACH [level] BY [time]" alone (Kraft, 2014). A later analysis of the relation between conditional clearances and altitude deviations examined reports submitted to the Aviation Safety Reporting System (ASRS), CPDLC communications in United States oceanic airspace from 2014-2017, LHDs in North Atlantic airspace, and altitude deviations reported in the New York oceanic airspace (Lennertz et al., 2019). The results of this study replicated the results of

Kraft (2014)- while the frequency of use of the combination of clearances of “AT [time] CLIMB TO [level]” combined with the “CLIMB TO REACH [level] BY [time]” varied across facilities, the type of pilot error was consistent—flightcrews climbed too early. Furthermore, the error was more likely when the message was issued via CPDLC rather than voice. As the authors note, voice communications allow the opportunity to emphasize critical factors (such as AT TIME) whereas such emphasis is not possible with a clearance issued via CPDLC. The analysis of ASRS reports confirmed that the most likely cause of pilot error resulting from the “AT [time] CLIMB TO [level]” and “CLIMB TO REACH [level] BY [time]” combination of clearances is that the pilots overlook the first clearance and only “see” the second. Furthermore, while the number of reported deviations has declined over time, the proportion of deviations involving conditional clearances remains comparable.

5.3 The North Atlantic Systems Planning Group (NAT SPG)

The North Atlantic Systems Planning Group (NAT SPG) Annual Safety Report offers a detailed analysis of lateral and vertical deviations (LHDs) in the NAT airspace. During 2020, 133 of these events were reported in the NAT High Level Airspace (HLA) of OCA of Shanwick, Santa Maria, Reykjavik, New York East, Gander and Bodo (ICAO NAT SPG, 2021). These events were categorized as 47 LHDs and 57 lateral deviations. The lateral deviations included 15 Gross Navigation Errors (GNEs), which are lateral deviations of 10 NM or more, and 13 ATC interventions where the lateral deviation was caught and corrected by ATC before it developed into a GNE. The report identifies the top 10 causal factors of the observed events but does not differentiate causal factors for GNEs vs LHDs. Only one causal factor was identified for each event.

The most commonly identified causal factor of GNEs and LHDs was ATC coordination. Errors in coordination between two ATC sectors or Air Navigation Service Providers contributed to 24 (18%) of the events of 2020. Errors associated with dispatch service, such as a route being incorrectly filed, contributed to 11 (8%) of the events. The remainder of the factors identified were related to flightcrew errors and are summarized below:

Flight Plan vs. Clearance. The most common factor identified was flying or intending to fly the planned route instead of the clearance. Errors involving flying the flight plan instead of the clearance were involved in 24 (18%) of the reported events. In most cases (19 out of the 24), these errors did not result in lateral deviations as they were caught (either through an Automatic Dependent Surveillance-Contract conformance alert or a CPDLC uplink/downlink route confirmation) and were prevented by ATC.

Non-compliance with ATC clearance. In 17% of the events, the pilot did not adhere to ATC clearances in either the vertical or the lateral dimension, for reasons that could not be determined by the information in the report. An additional 10 (8%) of the events, were separately classified as insufficient information.

Weather. Weather conditions experienced during the flight were identified as a factor in 15

(11%) of the events; these events were classified separately from the additional 8 (6%) of the events in which pilots deviated from their assigned clearance due to an emergency situation but did not follow the correct procedure for inflight contingencies in Oceanic Airspace.

Waypoint insertion. Errors involving the entry, update, or deletion of waypoints contributed to nine (7%) of the events.

Readback/Hearback voice communication errors. Instances in which a pilot incorrectly readback the clearance and the controller failed to correct the error contributed to seven (5%) of the events.

Confusion over CPDLC route message. Errors associated with misreading, misunderstanding, or a pilot report of an 'issue with their CPDLC' involving one of the following three messages contributed to seven (5%) of the events:

- UM79 CLEARED TO (position) VIA (route clearance)
- UM80 CLEARED (route clearance)
- UM83 AT (position) CLEARED (route clearance)

5.4 Flight Deck Human Factors Issues in Lateral Deviations during NAT Flight Operations

While the NAT SPG Annual Safety Report describes certain characteristics of pilot deviations in the North Atlantic, it does not contain insights into specific factors that contributed to the errors. Chandra, Kendra, Zuschlag, and Whittaker-Walker (2020) offer a more comprehensive examination of the human factors that contribute to pilot errors that result in lateral deviations. Of particular relevance to the topic of clearance negotiation (and correct execution of the negotiated clearance) are the issues associated with flight deck displays, waypoint naming, and route type (random vs. oceanic tracks).

Flight deck displays. It is well known that flight deck displays (e.g., as the display on the Flight Management System) vary in important ways, such as size, resolution, maximum number of characters displayed, etc. It is important to note that exactly how a clearance will be displayed on a flight deck cannot be surmised by the aircraft type and model alone (Chandra et al., 2020). The presentation of a clearance will vary as a function of the hardware and the software version that is installed in the avionics. This means that there can be variations even within a given aircraft fleet for a given operator.

Waypoint labels. Waypoint labels used on the flight deck for unnamed waypoints are an area of human factors concern because they may be abbreviated and are not standardized; this can result in a problem if the crew uses them without expanding the waypoints. Chandra et al. (2020) describe five ways in which this lack of standardization can contribute to pilot error:

1. Unknown Coordinates of User-Defined Waypoints. While it is operationally convenient to be able to use waypoints created by the operator, pilots may not remember the naming convention for these 'user-defined' waypoints. If the coordinates of these user-defined waypoints are not expanded to review the route, errors in using the waypoint, or in communicating the route to

ATC, could result. Since user-defined waypoints are also unpublished, they cannot be verified with a published chart.

2. ARINC 424 naming convention. The ARINC 424 naming convention that uses a prefix versus suffix letter code to distinguish half-degree waypoints from whole degree waypoints is non-intuitive and has led to error. Pilots have reversed the meaning of the letter code mistaking a half-degree waypoint for a whole waypoint and vice versa (Cardosi & Abbott, 2014). The non-intuitive meaning of the position of the N relative to the numbers is also problematic from a human factors standpoint. For example, 5050N is used to convey 50°N/50°W, while N5050 is used to convey 50°30'N/50°W.

3. Translation across Different Systems and Users. The lack of standardization in waypoint names is fertile ground for different meanings of the same waypoint being perceived by different users – pilots, dispatch, ATC – all of whom have a need to have the same understanding of a given route.

4. Display Label Ambiguity due to Truncating/Rounding. When the display label is either rounded or truncated to seven characters, the existence of the half-degree of latitude is hidden in the displayed label until it is expanded. Relying on the label (or the memory of its meaning) could lead to error.

5. Double Longitude Waypoint Insertion Error. The error occurs when pilots manually enter a partial-degree waypoint when given a whole degree waypoint, causing the longitude value to be entered twice (once as the longitude and again as minutes added to the latitude). This error occurs either because the pilot misreads the coordinate or manually enters the data incorrectly.

Random vs. oceanic tracks. More GNEs are found with aircraft on random routes than those using standardized routes on the oceanic track system. Chandra et al. (2020) note that random routes are more likely to be revised than routes on the track systems – each revision presents additional opportunities for error. The authors also observed that often only a single waypoint coordinate was modified in a reroute; such small differences are difficult to detect. The reasons that more errors are observed on random routes than on oceanic tracks, and the exact nature of the errors, need to be systematically examined. The results of such an analysis would not only serve to point to error mitigation strategies for re-routes in today's operations but could also be key in helping to minimize pilot error in the negotiation process in the future.

6. Analysis of Mandatory Occurrence Reports (MORs)

FAA provided Volpe with the results of a search of oceanic MORs that was conducted on June 28, 2021, for reports submitted from January 1, 2018, to the present. This search captured all of the reports for which the "oceanic" data field search indicated 'yes' and yielded 370 reports. Of the 370 reports, only 38 were pilot deviations (no additional reports were identified as 'possible pilot deviations'). Of these 38 pilot deviations, seven involved a pilot request for a change in trajectory transmitted via CPDLC.

To supplement these data, FAA also provided Volpe with the results of a search of MORs of Pilot Deviations in en route airspace. This search captured all the events for which the narrative indicated that the event occurred in oceanic or 'non-radar' airspace, but the data field 'oceanic airspace' (Y/N) was not answered. This search was conducted on July 7, 2021, for reports submitted from January 1, 2018, to present and yielded 3,796 reports. For each report in the combined data set, three data fields were analyzed: "Pilot Deviation Summary", "Summary", and "QA (Quality Assurance) Summary". Excerpts and synopses of reports relevant to clearance negotiation are presented here and referenced with either the Pilot Deviation number (e.g., PEACZNY20003) or the CEDAR report identification (e.g., ZNY-M-2020/01/22-0003).

Aircraft identifications have been replaced with "AC" and sector numbers have been replaced with "ATC" or "controller". Where audio files were attached to the written MORs, the relevant audio files were reviewed, and the results incorporated into this analysis.

Pilot requests for a change of altitude or route can be due to turbulence, to avoid adverse weather, or to increase the efficiency of flight. The aspects of the clearances used in clearance negotiation associated with flightcrew errors fall into the following categories:

Visual and Cognitive Complexity

- Misreading a clearance - this includes errors due to 'seeing' the clearance they were expecting rather than the actual clearance and failure to detect differences in the revised clearance from what has already been entered into the FMS.
- Interpreting an informative message as a clearance.
- Interpreting a question from ATC as a clearance - these errors often occur with the pilot's use of free text or voice to reply to controller's inquiry instead of selecting the standard reply message.

Technical Complexity

- Difficulty in programming the clearance into the FMS or reviewing the clearance entered into the FMS. This includes data entry errors (i.e., 'fat finger' errors) and errors due to partial or inaccurate loads while using the LOAD prompt on the FMS.

It should be noted that what appears to be the same type of flightcrew error can be due to different aspects of complexity. For example, in this data set, there were multiple instances of pilots flying the flight plan instead of the clearance. Indeed, the most common type of flightcrew error reported in North Atlantic oceanic airspace involves pilots following all or part of the flight plan instead of the actual clearance (Chandra et al., 2020). When clearances are delivered via CPDLC, this error can be due to pilots not detecting any difference between the 'revised' clearance and what they have already entered into the FMS, forgetting to load the new clearance, making a data entry error when loading the clearance, or forgetting to execute the new clearance. Below are synopses of events that exemplify this type or error.

- AC turned direct WILYY intersection, part of the original route, without ATC clearance, losing separation with AC2. (PEATJFK19011)
- In Oceanic Airspace. AC at Flight Level (FL) 330 and started climb to FL340. When asked by ATC why they climbed to FL340, AC said that they "misunderstood clearance compared to filed" clearance. The Brasher warning[2] was issued. (ZNY-M-2018/05/12-0003)
- AC was approved FL410 and made a request to climb to FL430. AC climbed without clearance from ATC to FL430. Pilot stated via free text that he 'CLIMB TO FL430 'PER OUR FLT PLAN'. (PCEZ0920005)

This occurred in en route airspace as well as in oceanic airspace:

- When questioned by the controller, the pilot read back the filed routing rather than the routing they had been given as a revised clearance. (ZLA-M-2016/09/05-0005)
- "CPDLC WILCO message was received from the crew. The flight flew the originally cleared route of flight." (PALCZAN19001)

The reports of pilot deviations that involved a pilot request for a change in altitude or route that was transmitted via CPDLC will be described here as well as additional reports that shed light on other errors that pilots could make in clearance negotiation.

6.1 Visual and Cognitive Complexity

As previously discussed, visual and cognitive complexities in CPDLC clearances can result in errors due to pilots misreading a clearance, interpreting an informative message as a clearance, or interpreting a question from ATC as a clearance.

6.1.1 Misreading a Clearance

While there were several reports of pilots misreading controller messages, only one involved a request for a climb due to weather. In this case the pilot was at FL380 and requested FL390 due to weather. One minute later, ATC advised via CPDLC "UNABLE HIGHER ALTITUDE DUE TO TRAFFIC… REQ [REQUEST] ON FILE" Three minutes later, the aircraft was observed at FL384, resulting in a non-radar loss of separation. During the call to the facility, the pilot of the air carrier aircraft stated, "they misread the ATC response" (PNMZ00220014). As described, there is nothing about the controller's message that can account for the error. If, indeed, it was 'misread', this was likely due solely to the pilots' hopeful expectation for the

[2] The Brasher warning (or Brasher notification) notifies the pilot that he/she may have been involved in a pilot deviation. The intent is "…to make note of the occurrence and collect their thoughts for future coordination with Flight Standards regarding enforcement actions or operator training." (Ref. FAA Order JO 7210.632, Air Traffic Organization Occurrence Reporting, Paragraph 3-1 Note).

clearance.

The following example is more understandable. Since “Climb via the SID [Standard Instrument Departure], except maintain [altitude]” is currently used as a voice clearance, the following error seems predictable:

AC was issued “CLIMB VIA THE SID, EXPECT ONE SIX THOUSAND, ONE ZERO MINUTES AFTER DEPARTURE”. The pilot understood the clearance to be “CLIMB VIA SID, EXCEPT MAINTAIN ONE SIX THOUSAND”. (PNMCZDV18011)

In one case, the pilot started the climb at the time that they should have achieved the higher altitude.

- “AC requested FL370. At approximately 2208Z, the ATC instructed AC to climb to FL370, be level at or before 2217Z. AC responded “WILCO”. At 2217Z, AC was leaving FL352 and reported level FL370 at 2220Z.” (PFSZ05719003)

Frequently, the pilot who has made a request is predisposed to see the altitude that was requested as the cleared altitude.

- Pilot requested altitude block FL340 to FL360 due to aircraft performance and weather. ATC issued a “CLIMB TO AND MAINTAIN BLOCK FL340 TO FL350”. Pilot responded with “WILCO” and “sometime later” the aircraft was at FL359. Pilot called and stated that after reviewing the messages, they realized that they misread the message sent by ATC and climbed to the wrong altitude. (PNMZ00219012)

- AC at FL350 requested block altitude of FL300 to FL310 reporting moderate chop at FL350. The controller coordinated with another sector for the altitude change and issued AC to maintain block FL330B350 (FL330 to FL350) and stated, “unable any lower due to traffic”. The aircraft sent the message “WILCO” to the clearance but was observed at FL327. The controller asked the pilot to confirm altitude saying, “I'm showing you at FL327 and you have traffic below at FL320”. The controller then tells the pilot to maintain FL330B350. At 0130Z AC said we are at FL300. At 0131Z the controller cleared AC to maintain FL300 and stated that the pilot was never assigned a lower altitude and that they were cleared to maintain FL330B350. The controller asked the reason for the descent and the pilot said they were cleared to FL300B310. (PWPCZOA21002)

- AC was at FL370 and requested a climb to FL390. ATC cleared AC to climb to and maintain FL380, report level FL380. ATC received an out of conformance message as aircraft climbed to FL390. (PWPCZOA18034)

- AC requested a climb to FL340 from FL320 via CPDLC. ATC issued a climb to FL330 via CPDLC. Aircraft responded with “WILCO.” A few moments later, AC was observed climbing through FL337. (PALCZAN16027)

- AC at FL410 requested FL430 and was advised, “UNABLE DUE TO TRAFFIC”. When an Automatic Dependent Surveillance (ADS) position report indicated AC was at FL420, a clearance was issued to “MAINTAIN FL410”. Pilot thought they had received a CPDLC clearance to FL430. Pilot stated that this was their first datalink flight. (WCZOA19006)

- At 1718Z, AC1 via CPDLC requested a climb to FL340 from FL320. AC2, approximately 50 miles south of AC1, same direction, but merging targets, was at FL340. ATC issued a climb to FL330 to AC1 via CPDLC. Aircraft responded with "WILCO", but 'a few moments later' was observed climbing through FL337 and now in conflict with AC2. (PALCZAN16027)

It should be noted here that the same type of error is seen with oceanic voice communications. For example, AC requested FL330, was issued FL300 and told to report level. Pilot read back (via oceanic) FL300 and report level. Reported level at FL330. (ZOA-M-2018/04/03-0001)

The following reports do not specify which messages were used, so the nature of the error is unclear:

- Pilot was at FL320 and requested a climb to FL340 with RJJJ (Fukuoka). Pilot misread the message from RJJJ and climbed from FL320 to FL340. Pilot checked in with ZAN, west of PASRO, at FL340, when altitude coordinated between RJJJ and ZAN was FL320. Pilot admitted on frequency to making an error and gave "miscommunication with his request" for FL340 as reason for the deviation. RJJJ claims no climb was issued. (PSWTDFW20007)

- AC at FL240 at 1107Z Requested climb to FL260. When ZNY called GANDER to coordinate climb to FL260, GANDER Low did not see flight on cleared route but noticed a flight approaching RAFIN on a 2000 Code[3]…. ZNY was notified by GANDER Low at 1117Z that flight was over RAFIN at FL258. (PEACZNY20015)

Pilots report that they have occasionally received 'revisions' that are no different than the previously received clearance (G. McMullin, personal communication, 2021). While this is not a common occurrence, it sets the stage for pilots to assume the 'revised' clearance is what they have already received, particularly if the differences between the two clearances are small and difficult to notice. Several reports describe situations in which the pilots fail to detect the difference between the clearance they just received and the clearance that they had already entered into the FMS:

- "The pilot stated that he and the copilot were reviewing the flight plan and the reissued clearance, and they both thought that that MQO was not in the amended clearance as well." (PWPCZLA16086)

- "The pilot said that they did not catch the difference in routing from what they believed was filed and the clearance. The pilot realized it was their error." (PWPCZLA16004)"After being issued CLEARED TO AIR VIA ROUTE CLEARANCE, AC made an unauthorized turn direct AIR. Pilot stated that it was an expectation bias situation. 'I assumed it was via our original route clearance. I did not see the bottom line with the one and only mention of APE preceding AIR, nor did the pilot flying. We were not expecting a fix that was not on our original clearance.'" (PGLCZID20024)

[3] ICAO Doc 4444: Paragraph 8.5.2.2.8 "Except for aircraft in a state of emergency, or during communication failure or unlawful interference situations, and unless otherwise agreed by regional air navigation agreement or between a transferring and an accepting ATC unit, the transferring unit shall assign Code A2000 to a controlled flight prior to transfer of communications."

- "During call in, pilot stated, that previously any change in routing would give them a "revised clearance" message. He said that as of 8/12/2016 they now receive a "load new route"[4] message. He said that since he did not see "revised" that he did not believe that they had a different routing." (ZLA-M-2016/09/05-0003)

Interestingly, the "LOAD NEW ROUTE" free text message had been added by the ground system to try to mitigate errors observed in the en route environment in which pilots were not recognizing that they had been sent a revised route.

By far, the most common errors seen with pilots misreading the clearance in this MOR data set involved conditional clearances. Recall that conditional clearances are defined as clearances that include a restriction, such as a time or place for starting the climb or descent, and/or a place or time for when the altitude (i.e., [level]) is to be reached (Kraft, 2014). The CLIMB TO REACH [level] BY [time] clearance is the most frequently used conditional clearance in oceanic airspace and is usually complied with (Kraft, 2014). The following report is an exception:

- After receiving the message CLIMB TO REACH FL360 BY 01:25Z// REPORT MAINTAINING FL360, the crew replied, "WILCO" and "inserted a time marker in order to comply with the clearance. The crew then resumed with the approach preparation and briefing while entering USA domestic airspace. Due to the distraction caused by the briefing, the crew didn't comply with the clearance at the established time." (PEACZNY20012)

Similarly, the clearance to CLIMB TO REACH [altitude] by [position] is not known to be problematic. The factors that contributed to the following error could not be determined.

- AC was instructed to be level at FL370 by 40W, responded "WILCO" but crossed 40W at FL360. When ATC asked why the AC did not comply with the clearance, the pilot responded with 'Roger'. (PEACZNY21002)

The AT [time] restriction has long been identified by pilots as particularly problematic since either acting on the clearance when it is received or forgetting to act on the clearance at the appropriate time results in an error. Most often, however, the aircraft climbs early.

- AC was issued clearance to MAINTAIN FL290, AT 2335Z CLIMB TO AND MAINTAIN FL300 DUE TO TRAFFIC. AC responded "WILCO", but climbed and reported level at 2327Z. When queried about the assigned altitude, AC descended back down to FL290. (ZOA-M-2018/02/08-0003)

- AC requested via CPDLC CLIMB TO FL350. Five minutes later AC was issued "MAINTAIN FL330, AT 0029 CLIMB TO AND MAINTAIN FL350, REPORT LEVEL FL350". AT 0025, AC responded with "WILCO" and reported level at FL350 at 0028. Pilot stated that the first officer misread the clearance to the captain. (ZOA-M-2018/04/21-0001)

[4] Note—in the US, this additional text of "load new route" can only be included on domestic route clearances; oceanic clearances do not include this additional free text.

- AC1 requested climb to FL400. Traffic at FL400 was AC2. The controller issued "AT [time] CLIMB…" to AC1 which would provide appropriate separation from AC2. AC1 climbed to FL400 shortly after receiving the clearance before the aircraft was supposed to climb causing a validated loss of standard separation. … "The pilot called the landline via SATPHONE and apologized stating he was at fault and had read the clearance incorrectly. He also stated that in the 6 years of flying with CPDLC and in Oceanic airspace that this was the first time he had received a[n] AT TIME climb clearance." (PEACZNY20003)
- This case of a pilot climbing early after being issued a conditional clearance was more complex than the summary of the pilot deviation indicated. The summary stated that the aircraft, "At FL360 had a climb clearance to FL430 to start at 1429Z. The aircraft reported level at FL430 at 1422Z…". While it is true that the pilot missed the "AT [TIME]" portion of the clearance and climbed early, it is also the case that the pilot requested FL430 in response to the controller's non-standard clearance negotiation message (sent via free text) "HOW HIGH ARE YOU REQUESTING". The pilot responded with 'REQUEST CLIMB TO FL430'. While the controller should have responded to this request with UNABLE before issuing a similar clearance, instead, the response is 'CLIMB TO REACH FL360 by 1412Z', which the pilot responded to correctly. At 1413Z, the controller sent 'PROCEED DIRECT TROUT, MAINTAIN FL360, AT 1429 CLIMB TO AND MAINTAIN FL430, CLIMB TO REACH FL430 BY 1440Z (CORPEACZNY16041). The fact that this surprisingly complex clearance ended with a common instruction, to which the pilots are accustomed to acting on immediately likely contributed to the error.

As discussed, an in-depth investigation into the use of conditional clearances showed that the use of the AT [time] restriction is less of a problem than the use of the combination of AT [time] CLIMB/DESCEND TO [level]" and "CLIMB/DESCEND TO REACH [level] BY [time] (Kraft, 2014; Lennertz et al., 2019) and is often issued in response to a pilot request.

- AC at FL360, request climb to FL380. Two minutes later (at 1742), ATC clears AC to MAINTAIN FL360, AT 1755 CLIMB TO MAINTAIN FL380, CLIMB TO REACH FL380 BY 1802, REPORT LEVEL FL380. Two minutes later AC reports level via CPDLC at FL380. (PEACZNY20002)
- AC requested FL390. At 0214:50 the controller instructed AC to begin climb to FL380 at 0231Z and be level at FL380 by 0241Z. AC responded "WILCO". At 0217:05, AC reported level at FL380. (PEACZNY15037)
- AC requested FL390 and was issued "MAINTAIN FL380, AT 0205 CLIMB TO AND MAINTAIN FL390, CLIMB TO REACH FL390 BY 0210, REPORT LEVEL FL390, DUE TO TRAFFIC". At 0145 AC reported level at FL390 (PEACZNY16001).
- AC requested FL390 and was issued, "MAINTAIN FL380, AT 0430Z CLIMB TO AND MAINTAIN FL390, CLIMB TO REACH FL390 BY 0435Z, REPORT LEVEL AT FL390". At 0412 AC was at FL390. (ZNY-M-2016/04/11-0001)
- AC requested FL360 at 2142. Controller issued "unable due to traffic". At 2254Z controller issued clearance "MAINTAIN FL350, AT 2320 CLIMB TO AND MAINTAIN FL360, CLIMB TO REACH FL360

BY 2330, REPORT LEVEL FL360". Aircraft replied "WILCO" at 2255Z. At 2257z aircraft reported "LEVEL FL360". (PEACZNY17013)

- At approximately 1940Z, the ATC instructed AC to maintain FL360 until 1950Z, then climb and maintain FL390, be level at 1957Z, report reaching. AC responded "WILCO", but climbed to FL390 "almost immediately" after receiving the clearance (and before 1950Z). (PEACZNY19001)
- AC was in Oceanic airspace at FL380. ATC instructed AC to maintain FL380 until 2142Z, then climb to FL400, be level at FL400 at 2146Z, report level. AC acknowledged the clearance with a "WILCO" but began the climb before 2142Z. (PSOTSJU19004)
- ATC instructed AC at 1145Z to maintain FL320 until 1157Z, then climb to FL360 by 1210Z, report reaching. AC acknowledged with a "WILCO" but began to climb before 1157Z. (PEACZNY19003)
- At 23:12:28Z AC requested FL380. The controller servicing the airspace responded Unable due to traffic at 23:13.15Z. At 23:18:20Z the controller issued the following clearance: Maintain FL360; at 2325Z climb to and maintain FL380. Climb to reach FL380 by 2335Z; Report level FL380. At 23:18:37Z AC requested to deviate up to 30 NM left of course. At 23:19:12Z AC responded, "WILCO" to the clearance to climb. At 23:19:41Z the controller responded, cleared to deviate up to L 030 NM of route. At 23:20:01 AC responded WILCO. Then at 23:20:33Z the controller received an ADS automatic position report that identified AC at 37,916 ft. At 23:20:43 the controller received another ADS positioning report of the aircraft reaching an altitude of 37,952 feet. At 23:21:07Z the controller received an ADS positioning report of the aircraft reaching an altitude of 38,004 ft. It's very difficult to determine the exact time the pilot climbed to his requested altitude of FL380; but it was obviously before his assigned clearance to begin his climb because he showed level more than 1 minute and 30 seconds prior to his clearance to climb. (PEACZNY16043)
- AC "requested a climb to FL360. Due to faster traffic behind him, at 17:50:49Z the controller servicing the airspace advised AC that they could not accommodate his altitude request. At 19:56:57Z ATC sent a CPDLC message, which stated: "At 2005Z descend to and maintain FL340, descend to reach FL340 by 2009Z, report leveled at FL340". It shall be noted that AC was required at an altitude that was appropriate for his direction of flight prior to entering ZMAs radar-controlled airspace. Because of these dynamics, FL340 was the highest available altitude that was appropriate for his direction of flight. At 19:59:55Z the PIC of AC reported leveled at FL340. Apparently, he descended early and leveled at FL340 6 minutes prior to the time he was cleared to descend." (PEACZNY17008)

This incident also shows the strength of the inclination to act immediately on the commonly issued "CLIMB/DESCEND TO REACH [altitude] BY [time]" and forget or fail to notice the "AT [time]" precursor. To be clear, pilots get accustomed to maneuvering upon seeing the clearance "CLIMB TO REACH [altitude] BY [time]" because of its frequency; only rarely– and only in oceanic airspace in the United States – is it paired with "AT [time] CLIMB TO [altitude]". A study of the frequency of use of conditional clearances found that the instruction to "CLIMB/DESCEND TO REACH [altitude] BY [time]" was issued 43 times more frequently than "AT [time] CLIMB TO [altitude]" (Lennertz et al., 2019). Yet, the number of large height deviations associated with the combination of these two clearances result in more errors than either of the two messages when presented alone (Kraft, 2014).

6.1.2 Interpreting an Informative Message as a Clearance

"While EXPECT message elements can be useful for planning purposes, they can lead to operational errors when pilots mistakenly interpret them as a clearance."
Global Operational Data Link (GOLD) Manual *(ICAO Doc 10037, 2017, p.3-11)*

This data set contained only one error in which a flightcrew interpreted an EXPECT message, issued via CPDLC, as a clearance:

- AC at FL380 requested FL410. Controller issued "MAINTAIN M.78 FOR YOUR CLIMB EXPECT NORMAL SPEED AT FL410". AC "appeared to have interpreted that as a clearance and climbed to FL410" (PWPCZOA18074)

However, the data set also included similar errors involving voice communications:

- AC was level at 5,000' and requested lower. ATC advised pilot to expect lower in 90 seconds. Pilot responded "OK". AC was observed descending out of 4,600'. (PSOCZMA17035)
- At 1809Z ATC asked AC if he'd prefer to move to FL260 or 280 for direction of flight. AC responded "Alright, we'll go to FL260" and the controller said, "you can expect that". At 1810 AC was observed descending, was asked if he was level at FL270, to which the pilot responded that he was descending to FL260. (ZTL-M-2020/12/22-0003)
- AC was issued a climb clearance to FL370 and to expect direct ENL. AC read back clearance correctly. AC began climb and executed direct ENL. (PWPCZLA18107)
- Pilot said that the controller advised him of his new route and stated that he needed to be at an even altitude of 8,000' or 10,000'. Pilot said he will go to 10,000'. ATC advised pilot to expect that. He said he thought that since he said he wanted 10,000', he was assigned 10,000'. (PSOCZMA17)
- AC checked on frequency and asked about getting a shortcut. The controller stated that he needed to move the aircraft up or down. The aircraft asked about the rides and the controller got a pilot report that FL360 was a good ride. The pilot stated that they would take FL360, and the controller responded by saying "standby for that". AC is then observed leaving FL370 …Pilot stated that they thought they were given a clearance to descend. (PSOCZTL21017)

EXPECT messages in FANS are worded like clearances. Due to errors involving pilots interpreting the message "EXPECT [altitude]" being interpreted as a clearance, ICAO made changes to the recommended dialog. ICAO (Doc 10037, 2017) states that the flightcrew should query the controller as to when a response can be expected using "WHEN CAN WE EXPECT [higher/lower]" messages. The controller then responds with "YOU CAN EXPECT AT [time/position]". By specifying 'higher' or 'lower' rather than a specific altitude, it precludes the pilot interpreting it as a clearance.

The following instance demonstrates how communications conducted through third-party voice (ARINC) can add another level of variability:

- AC requested FL360 and was told to MAINTAIN M078 OR LESS FOR THE CLIMB. (Note that while MAINTAIN M078 is a standard message, MAINTAIN M078 OR LESS FOR THE CLIMB is not.) "There were some questions back and forth about whether that speed would apply when at FL360 or just in the climb, AC replied that they would prefer to remain at FL350 and at M081. Controller stated that the speed would be required in either case and that normal speed would be assigned ASAP." AC climbed to FL360 without an ATC clearance and increased their speed to MACH 0.81, which was their normal speed. At 2251Z, controller issued again, FOR YOUR CLIMB, MAINTAIN M078 OR LESS, NORMAL SPEED ASAP. AC read back ASSUMING NORMAL SPEED IS M081 AT FL360, WE WILL MAINTAIN FL360 AND WE ARE THERE NOW. SFO ARINC called (ATC) and advised that their communication with AC may have contributed to the confusion surrounding this event." (PWPCZOA18082)

6.1.3 Interpreting a Question from ATC as a Clearance

As noted by Mueller and Lozito (2008), pilots may assume that the controller would only inquire if the change in altitude or course was feasible and available. This could contribute to a pilot misinterpreting a question as a clearance. Examples of this occurring with voice communications include:

- At 2113Z, controller asked AC if he'd be able to accept 160 in about 40nm for terrain. Pilot concurred, unless there was icing. At 2114:50 AC started a climb. (PSWCZAB20011)

- AC was inbound to KRIL "at FL140". Controller asked pilot if he could "get the visual" if controller turned him toward the airport. Pilot stated that he could. Controller then cleared AC direct to KRIL, but had not issued a visual approach clearance to aircraft. Aircraft made right turn to the south to head toward KRIL. Pilot stated that he misunderstood the controller's question ("can you get the visual") for a clearance to conduct the visual approach into KRIL and initiated his descent based on that understanding. (PNMCZDV20015).

- Pilot was asked if he was "able 3-6-0 for traffic". Pilot responded "3-6-0 works" and initiated the climb without a clearance. (PNMTDEN08009).

The advantages to using CPDLC for such negotiations include that the messages are more constrained (and thus, less variable) and that the inquiry from the controller prompts a response from a pilot. Most importantly, there are features of FANS that are designed to mitigate such errors. When presented with a question, such as "WHEN CAN YOU ACCEPT [altitude]", flightcrews should compose the response from those preformatted messages in the system designed for that specific purpose, rather than composing a response using free text or responding via voice. These errors often occur with the pilot's use of free text or voice to reply to controller's inquiry instead of selecting the standard preformatted reply message.

In the following MORs, the flightcrews did not use the proper response:

- AC was in an oceanic environment level at FL380, and the controller asked the pilot when they could accept FL390. Via CPDLC, the pilot responded that they were able to “do it now.” [and started climbing without a clearance] The controller did not issue a clearance prior to AC climbing to FL390. (PNMZ00220025)
- ATC asked AC “WHEN CAN YOU ACCEPT FL360”. AC responded and climbed to FL370 without a clearance. Pilot called and explained that he ‘misunderstood the question as an instruction to climb’. (PALCZAN18003)
- AC was at FL380 in oceanic airspace and was asked could they accept FL390. AC replies with “we can accept now” and climbed to FL390 without clearance from ATC. (PEACZNY19023)
- AT 22:03Z ATC asks AC “When can you accept F370?” One minute later an ADS report was received indicating AC was starting a climb. At 2205Z AC requests to climb to FL370 while the aircraft is still in a climb to FL370. At 2206Z ATC issues AC a clearance to climb to FL370 and at 2208Z AC responded “WILCO” to the climb; ATC then informs AC of the ADS report of the aircraft climbing prior to the issuance of the climb clearance. (PEACZNY18017)

While the following event was not filed as a pilot deviation, it is another example of confusion created by the use of free text instead of a standard message.

- “There was confusion regarding the deviation/clearance issued by RJJJ (Tokyo) as well as the CPDLC messages. After transfer from RJJJ, pilot initially contacted ZAK for unknown reasons before contacting ZAN. Pilot CPDLC message was also somewhat ambiguous when it showed: [WE ARE DEVIATING LEFT RIGHT NOW DUE TO WX WE WILL BE BACK ON CRS (course) IN 5 MILES AND WILL CALL BACK ON CRS RESENT TO ANC CNTR PREVLY SENT TO OAK CNTR]. Without punctuation it is unclear if pilot was deviating LEFT/RIGHT or… DEVIATING LEFT, RIGHT NOW… It is unknown what clearance(s) were issued by RJJJ. The pilot advised ATC of moderate turbulence in RJJJ airspace.” (ZAN-M-2020/03/11-0002)

It should be noted that the current FANS message set only allows pilots to select left or right as a direction for a weather deviation. The ATN Baseline 2 message set includes an option for the aircraft system to send the direction “left”, “right” or “either side”. When “either side” is requested, the message intent indicates that the flightcrew wants the flexibility to deviate either side of the cleared route.

However, even when the pilot uses the proper message for the response, there is the possibility for error:

- AC was asked when they could accept FL400. AC replied at 18502. A climb clearance was not issued. The controller cleared AC direct AVE. AC replied, “WILCO.” At 1859Z, the ADSB report from AC displayed this flight at FL400”. (PWPCZOA15049)

- AC at FL340 requests FL360 and was advised unable due to traffic. At 2003Z, ATC asks AC WHEN CAN YOU ACCEPT FL360. A minute later AC replies WE CAN ACCEPT FL360 AT 2004Z. Two minutes later, ATC issues CLIMB TO AND MAINTAIN FL350. AC responded “WILCO” to the clearance but flies to FL360. (PNMZ00219042)

It is likely that this error would not have occurred if the message that preceded the clearance had been WHEN CAN YOU ACCEPT FL350 instead of WHEN CAN YOU ACCEPT FL360. Both pilot and controller expectations need to be considered in the clearance negotiation process.

6.2 Technical Complexity

Many of the MORs describe errors in the execution, rather than the interpretation, of the clearance. These include pilot errors in loading the clearance into the FMS. Complex clearances (such as those that contain several datapoints specified with lat/long coordinates) that need to be manually entered into the FMS are subject to data entry errors, since each digit that needs to be entered presents an opportunity for error. The following are examples of errors in manual data entry:

- AC received clearance direct WLFMN and shortly thereafter began a left turn eastbound. Pilot said that the [First Officer] had incorrectly entered WLFMN YQO TPGUN TPGUN1. GGN7361 CYYZ./.4249N/08045W..YQO006002..WLFMN.TPGUN1. (PFSZ05819016)
- At approx. time 1515Z, controller noticed the AC off course. The controller was unable to ascertain from the pilot why the flight was tracking north of course so he requested a phone patch through ARINC at 1521Z. The routing discrepancy was still unresolved at the end of the call, but it was later discovered that the aircraft was cleared via flight plan to 38N060W but was flying to 3830N060W. (PEAZ02121003)
- FMS did not have the MDNYT arrival, and they entered it manually which made them bypass AMMOR. (PWPCZLA17129)
- Pilot Flying by mistake selected 4NM SLOP [Strategic Lateral Offset Procedure], the mistake wasn't detected by both pilots. (ZNY-M-2021/05/14-0001)
- Pilot stated the MYS transition was inadvertently loaded into the FMS. (PGLZ01119002)
- When the pilot was questioned, they stated that when he loaded the JAKIE STAR [Standard Terminal Arrival] he inadvertently dropped out the transition. (ZID-M-2017/05/21-0001)

While errors due to manual data entry are well known, errors involving loading a clearance with a LOAD prompt have yet to be fully explored. Clearances that can be loaded with a LOAD prompt in the FMS can reduce errors associated with manual data entry but can add complexity when only some of the portions of the clearance are loaded with the prompt. This means that the pilot must discern what portions of the clearance are loaded into the FMS and which need to be manually entered.

- AC accepted revised clearance at 2325Z. At 0040Z ATC recognizes AC was out of FL290 for FL310 turning towards MISEN intersection. Pilot stated that "they used a load option into the FMS that didn't take". (PWPCZLA18054)

The MORs associated with loading CPDLC clearances in the en route environment appear to underrepresent the number of such pilot errors. Errors associated with loading Uplink Message (UM) 79 [UM79 CLEARED TO (position) VIA (route clearance)] have been identified as a problem at several meetings of the FAA's Data Comm Implementation Team (DCIT). However, there are no data to indicate how often they occur. The most common error described with this message is that the aircraft flies direct to the named position. Other errors involved pilots loading the clearance with the LOAD prompt, but then failing to manually load the SID. As discussed in the DCIT meetings, these errors are due to pilots missing the load prompt, being more comfortable loading the clearance manually than using the LOAD prompt (especially if they were new to CPDLC) or interpreting the clearance as DIRECT TO the position. This type of error has also been identified as problematic in Europe. UM 79 is commonly used in the London FIR (EGTT) airspace (Michael Price, NATS, Data Link Users' Forum; September 13, 2021). To combat these errors, in en route, domestic airspace, the US appends a free text message (UM 169) of the complete routing. While it has been said that this addition 'seems to reduce errors', the US has no data that speaks to how effective this is in mitigating the errors (Chris Collings, Data Link Users' Forum; September 13, 2021).

The consequences of some automated functions can also introduce complexities in clearance execution. For example:

- AC was instructed to descend via the CHYSL2 arrival and received a good read back. The CHYSL2 arrival requires aircraft to cross BURRZ intersection between FL270 and FL240. AC descended below FL240 before BURRZ intersection without ATC clearance. Pilot said "they caught the early descent as the controller was calling them about it. They were in 'FMS Manage Mode'. Due to this incident, they were paying close attention to the FMS controlled descent and caught another error later in the approach where they had to override the FMS". (ZDC-M-2017/03/02-0006)

- When questioned, the pilot responded that the "incorrect flight path was due to wind correction". (ZDC-M-2017/01/10-0005)

Working around automated functions on the flight deck to adhere to a clearance can also lead to error:

- "…pilot advised that the FMS system on the aircraft is programmed to initiate a "smart turn" to intercept the arrival; even if it is before the initial approach fix. In order to force the aircraft to fly over KARSE, he needed to manually reestablish the routing for the RNAV approach, which he didn't do. In fact, he said they were both surprised when the aircraft made about a 180 degree turn back unto the arrival routing". (ZAB-M-2017/05/23-0002)

Pilots sometimes err in trying too hard to be accommodating. It is in a pilot's and controller's nature to make every attempt to 'make things work', but this approach can sometimes prove to be a mistake.

- At 1751.24Z AC requested a descent to FL390 due to a pressurization issue. The controller asked if the descent could accept a delay for traffic, which the pilot accepted. At 1752.54Z AC requested an immediate descent that the controller could not approve due to traffic. The controller began issuing vectors to expedite a descent however the aircraft descended without a clearance to FL427 causing a validated loss of standard separation. (ZTL-M-2021/06/19-0004)

'Work-arounds' should never include adding an unauthorized fix.

- A pilot stated that he was not cleared that way, but he turned toward SADDL to 'make it easier to set up for the ILS [Instrument Landing System]'. (PGLCZID17080)

Several errors were attributed (rightly or wrongly) to an FMS issue. For example:

- AC had correct routing but turned direct to a fix not on the arrival. When asked, pilot stated he had the above routing, but the FMS "dropped a point". (PGLCZAU16008)
- AC made an unauthorized turn of about 45 degrees. Pilot said he received the reroute, but it was "dropped by the FMS after a power cycle" and that he didn't notice until after the controller brought the unexpected turn to his attention. (PGLCZAU16039)

When controllers observe several same company aircraft make the same errors in a route, they suspect a systemic problem with the company's FMS.

- Aircraft turned direct NELIE after hitting PPORT. It appears the FMS dropped the rest of the PPORT1 Departure fixes. ... Possible systemic issue. Reference MOR ZBW-M-2015/11/08-0002 which happened yesterday. This was also a [same company] aircraft which turned direct NELIE after hitting PPORT. (PNECZBW15038)
- AC made an unexpected 20 degree left turn. 'Controller stated their belief that it is an issue with the company's FMS database'. (P-CE-C-ZKC-16-005). ATC advised that numerous flights of the same company were making the same routing error. (PCECZKC16007)
- "Pilot stated that clearance was entered correctly but after entering the ILS into the FMS, it "resequenced the data and picked up MYNN..WAVUN4. This is a known issue with the FMS". (PSOCZMA18087)
- AC made an unauthorized turn of about 45 degrees. Pilot stated that the FMS deleted two fixes out of his route causing the event. He said that this was found to be due to an 'anomaly in the FMS'. (PSWCZFW20017)

In summary, complex clearances that need to be manually entered into the FMS are subject to data entry errors, since each digit that needs to be entered presents an opportunity for error. Clearances that can be loaded with a LOAD prompt in the FMS can reduce errors associated with manual data entry but can add complexity when only some of the portions of the clearance are loaded with the LOAD prompt. This means that the pilot must discern what portions of the clearance are loaded into the FMS and which need to be manually entered. FMS issues have also been implicated in pilot errors in executing a clearance.

6.2.1 Weather

"Everybody talks about the weather but nobody seems to do anything about it."
Charles Dudley Warner

As flight efficiencies increase with the implementation of NextGen capabilities, and spacing between aircraft decreases, so too, do the degrees of freedom available to deal with the inevitable complexities due to weather. This speaks to the fact that contingencies due to weather need to be considered in all aspects of clearance negotiation. This data set contained several reports that involved a pilot request via CPDLC for a change in route or altitude due to weather. We have no data that speak to how often pilots are unable to get a clearance to maneuver around hazardous weather, since if the pilot declares an emergency or notifies ATC that they are maneuvering on the authority of the Pilot-in-Command (PIC), there is no pilot deviation. While unrelated to the complexity of the messages used, incorrect application of procedures for weather deviation is another factor in flightcrew errors. Many of the MORs describe events in which the pilot requested a deviation due to weather, but deviated before a clearance could be obtained, or exceeded the clearance issued, without following the proper procedure to act on the authority of the PIC. In some cases, even when the pilot informs ATC that they are deviating, ATC files a report so the event can be reviewed, particularly if there was a loss of prescribed separation. Below are the de-identified summarized incidents:

- AC requested 40 NM right of course due to weather. Three minutes later the controller responded that he was unable to issue the deviation due to traffic. Two minutes later, the flightcrew advised that they were executing a deviation 40 NM left of route. Shortly after, ARINC [the radio operator] contacted ATC to see if the controller was aware that the AC had executed a deviation without an ATC clearance. The controller immediately advised ARINC to advise the AC that traffic was in trail of him at FL360…. Although it was assumed, [the pilot] did not use the term Captains Authority prior to deviating and Brasher Warning was issued to the pilot in command. (ZNY-M-2017/07/28-0002)
- AC had requested to deviate for weather and was told unable. Pilot proceeded to deviate without clearance and without advising ATC they were doing so. Pilot did not declare an emergency or Pan-Pan-Pan. (PWPCZOA20003)
- AC was at FL360 when they requested a weather deviation 30 miles right of course. When the aircraft was observed deviating 35 miles (based on ADS position reports), ATC queried the pilot if they were requesting more than 30 NM right of course. The pilot responded "ROGER" (CPDLC). Twenty minutes after being issued the BRASHER, the pilot stated that at 30 miles right of course there was a cell that they had to deviate around and exercised captain's authority to do so. (PNMZ00219029)

- Pilot advised that he encountered turbulence and got distracted with getting cabin secure and passengers buckled up. Operating via HF radio, they thought that they had received a clearance and climbed from FL380 to FL400 to get out of turbulence. (PWPCZOA20014)

- AC at FL340 requested to deviate right of course for weather. Controller advised the pilot unable due to traffic and gave a clearance to deviate left of course. AC advised unable and deviated off course. Controller descended AC to FL330, and then approved deviations reaching FL330. (PEACZNY19006)

- AC requested to deviate left of course for weather. The controller replied that he was unable to approve deviation to the left, but rather deviation 20 degree right of course was approved. The pilot did not respond to the approval to deviate right of course and deviated left of course instead. All communications were relayed via CPDLC. (PEACZNY16025)

- AC requested via CPDLC to deviate right due to weather. The controller replied, "Unable to issue deviation clearance due to traffic...". The controller also advised that the conflicting traffic was 10 minutes in trail and at the same altitude. The controller then requested the pilot's intentions. The pilot responded, "Roger" and two minutes later stated that he could accept a left offset and proceeded to deviate 10 miles left of course. (PEACZNY16034)

- AC was at FL360 and requested FL380 for weather. The controller responded with UNABLE DUE TO TRAFFIC. Approximately a minute later, the controller received an air to ground message stating MOD TURB AT FL360 CLIMBING TO FL380 REQUESTING FL390. The controller then received a REQUEST TO CLIMB TO FL390 DUE TO WEATHER. AC later changed altitudes again without a clearance due to turbulence. The controller advised AC that 'Unless they are in an emergency, they need ATC clearance prior to changing altitudes'. AC did not declare an emergency but stated UNABLE TO SAFELY MAINTAIN FL360 DUE TO MOD/SEVERE TURBULENCE SMOOTH AT FL390. (PWPZ01321005)

- AC was at FL370 and AC2 was at FL360; both on deviation up to 40 NM left of track for weather. At 0339Z, the controller gets an ADSB hit on AC at FL360 and asks AC to confirm altitude. A minute later, AC confirms FL360. Another minute later, the controller tells AC your assigned altitude is FL370 not FL360 and that there is traffic at FL360. When the controller asked AC (via CPDLC) to say reason you descended to FL360, AC advised for turbulence. (PWPCZOA20019)

- AC requested deviation to the right. The request was not approved for traffic. However, AC turned to the right. (Neither the reason for the request, nor the messages used, were specified in the report). (PNMZ00221003)

- AC at FL380 requested a deviation 200 degrees left of course due to weather. Controller responded UNABLE and advised AC that they were only able to approve 128-degree deviations and any deviation further would require a reroute. Controller asked AC to advise when able FL390. AC advised he was able FL390 and controller issued clearance to FL390. Seven minutes after AC advised "CONTINGENCY PROC APPLIED DUE WEATHER AND OPERATION UNABLE TO

FILE NEW ROUTE DESCENDING FL 387 UP TO L200NM FROM ORIGINAL ROUTE". (PWPCZOA21004)

- AC requested a deviation left of course which would put aircraft into O21 airspace. Controller 1 coordinated with Controller 2 for deviation. Controller 2 was attempting to get control of the aircraft datablock since the aircraft was previously in O21 airspace. In the meantime, Controller 1 approved a 25-mile deviation (to keep the aircraft in the confines of his airspace) while trying to process the deviation. The two controllers tried for several minutes to make the two systems work together to provide separation. The AC was given a clearance to deviate 80 miles left of course M201 to return to course by UKOKA. Even though the aircraft was given a large deviation it turned up way beyond what the controllers approved and expected. (PEACZNY16009)

The North Atlantic airspace has prescribed flightcrew procedures to be used when a pilot needs to exercise the authority of a pilot-in-command to deviate from the clearance to avoid adverse weather in the North Atlantic airspace. This complex set of procedures is specified in its entirety in ICAO NAT Doc 007 (2022), *The North Atlantic Operations and Airspace Manual (p.102-103)*. Part of the procedure can be summarized as follows: *For deviations of less than 5 NM from the originally cleared track or route, the aircraft is to remain at a level assigned by ATC; for deviations greater than or equal 5 NM from the originally cleared track or route, the pilot should climb or descend 300 ft, depending on their heading, from normal cruising levels before deviating beyond the cleared distance. When flying east (heading 000-179), the pilot should descend 300 ft if deviating to the left and climb 300 ft if deviating to the right. When flying west (heading 180-359), the pilot should descend 300 ft if deviating to the right and climb 300 ft if deviating to the left.*

The procedures also stipulate that the pilot is to continue to attempt to contact ATC to obtain a clearance (if contact was not established prior to deviating) and to continue to keep ATC advised of intentions. If these procedures are followed, then no pilot deviation will be filed as a result of the failure to comply with the ATC clearance. There were two MORs that referenced this procedure:

- When questioned, AC responded, "We are suppose[d] to climb 300 feet when we deviate more than 10 miles off course" (to avoid hazardous weather). ATC informed the pilot that the '300-foot climb was in the event that the pilot declare Captains Authority'. AC climbed to FL343 without ATC clearance. The pilot later called ZNY and acknowledged that they had climbed in error. (PEACZNY16014)

- AC was in a non-radar environment and requested deviations left for weather. The controller stated that they were unable due to traffic. The pilot reported that they were deviating 20 degrees left and then was observed climbing 300 feet. When the pilot called in, they reported that it was standard procedure within the airline and with the NAT procedures. The NAT procedures do permit the aircraft to deviate and climb 300 feet; however, the NAT does not appear to cover this route. Brasher issued. (PWPCZOA21005)

6.3 Summary of Flightcrew Errors in Mandatory Occurrence Reports

This study reviewed over 4,000 MORs for flightcrew errors in clearance negotiation and other factors that could affect pilots' adhering to a negotiated clearance. It examined the steps needed to successfully execute a CPDLC clearance: to be read correctly, interpreted correctly, and then entered correctly into the FMS and defined the complexity of CPDLC clearances as the sum of factors that contribute to pilot errors associated with those clearances.

The analysis found several instances of pilots reading what they expected to see, going to an altitude that they had requested, and interpreting a question or statement from ATC as an implied clearance. By far, the most common error related to specific CPDLC clearances involved a known problem – that of a particular combination of conditional clearances. The combination of AT [time/position] CLIMB/DESCEND TO [level] and CLIMB/DESCEND TO REACH [level] BY [time/position] was first identified as problematic in 2010. The results of the current study show the strength of the inclination to act immediately on the commonly issued CLIMB/DESCEND TO REACH [altitude] BY [time] and forget or fail to notice the AT [time] precursor. It is clear that pilots get accustomed to maneuvering upon seeing the clearance CLIMB TO REACH [altitude] BY [time] due to its frequency, and the fact that only rarely – and only in oceanic airspace in the United States – is it paired with AT [time] CLIMB TO [altitude].

It is important to note that many of these MORs state that one pilot misread the clearance to the other pilot. It is unknown how many of these or other errors could have been prevented had crews followed the procedure recommended in the *GOLD* manual (ICAO Doc 10037, 2017) that both pilots should individually and silently read each CPDLC uplink message and discuss prior to responding to and/or executing any clearance. This procedure allows the same independent interpretation that voice communications afford: If one pilot were to read the message out loud, the second pilot would be vulnerable to also "reading" what the first pilot read aloud and missing any discrepancies between what was heard and the written clearance. A 2015 review of Standard Operating Procedures across seven carriers (including both domestic and international) found that only one carrier instructed their flightcrews to follow this "silent read" procedure. (Lennertz & Cardosi, 2015). Two carriers suggested that the message should be read out loud by the Pilot Monitoring (PM) and verified by the Pilot Flying (PF). Four of the seven carriers did not specify a procedure (Lennertz & Cardosi, 2015).

Difficulties in programming the clearance into the FMS or reviewing the clearance entered into the FMS were also examined. Often these involve errors in manual data entry as numbers are transposed or otherwise entered incorrectly into the FMS. While errors due to manual data entry are well understood, errors involving loading a clearance (e.g., with a LOAD prompt) have yet to be fully explored. Use of the LOAD prompt can reduce errors associated with manual data entry but can add complexity when only some portions of the clearance are loaded with the prompt. This means that the pilot must discern what portions of the clearance are loaded into the FMS and which need to be manually entered. The number of MORs associated with loading CPDLC clearances in the en route environment appears to underrepresent the number of such pilot errors. Errors associated with loading UM 79s [UM79 CLEARED TO (position) VIA (route clearance)] have been identified as a problem at several meetings of the DCIT.

However, there are no data to indicate how often they occur. The most common error described with this message is that the aircraft flies direct to the named position. Other errors involved pilots loading the clearance with the LOAD prompt, but then failing to manually load the SID. These errors could be due to pilots missing the LOAD prompt, being more comfortable loading the clearance manually than using the LOAD prompt (especially if they were new to CPDLC) or interpreting the clearance as DIRECT TO the position. Errors associated with use of the LOAD prompt are further explored in the analysis of ASRS reports.

Finally, there were several flightcrew errors that involved a pilot request for a change in route or altitude due to weather. These were largely due to the incorrect application of procedures for weather deviation; there were no indications that a clearance was misread or misunderstood in these cases.

7. Analysis of Reports Submitted to the ASRS

The only information on the pilot's perspective contained in MORs is that which may be reported by the pilot if they spoke to ATC about the event. Unfortunately, this information is only included in a small portion of the MORs. MORs underrepresent the number of pilot errors, particularly recent errors and those that do not result in a loss of standard separation between aircraft, since not all errors result in a reportable event and not all reportable events are actually reported. While ASRS reports cannot be used to determine how often errors occur, they contain insights as to the factors that the pilot considered to be relevant to the incident. To collect information from the pilot perspective to supplement the MOR data set, a search of reports submitted to the ASRS was conducted. The search criteria were:

- Reports submitted between May 2016 and May 2021,
- 14 CFR Part 121 Part 129 or Part 135 operations,
- Containing a reference to Controller-Pilot Data Link Communications (as search terms "CPDLC", "Data Comm', "Data link"),
- Reporter function: Captain, Check Pilot, First Officer, Flight Engineer/ Second Officer, Pilot Flying, Pilot Not Flying, and
- Event type was "excursion from assigned altitude or clearance".

This search yielded 85 relevant reports. Many of the reports mirror incidents seen in the MORs but include pilot insights as to the causal and contributing factors. Other reports describe errors or situations not seen in MORs that are relevant to clearance negotiation. Taken together, these reports contain a wealth of insights into factors that should be considered in clearance negotiation in current and future operations.

7.1 Pilot Errors associated with Departure Clearances (DCL)

There are trends in the types of errors that were reported with CPDLC over time; this is most noticeable in the reports involving CPDLC DCL – the Departure Clearance application of data link. This data set contained several errors (from 2015 and 2016) that describe a general confusion of pilots new to DCL (1371949, 1380581, 1374229, 1353230, & 1348267). Most of the reports involving DCL relate to clearance negotiation only in the general sense of human factors issues that arise with the implementation of new procedures. For example, the following report directly related this general confusion noted with DCL to a lack of training:

- Upon departure ATC told us to "use your ACARS [Aircraft Communications Addressing and Reporting System]" to get clearance. There was no PDC [pre-departure clearance]. There was a note about datalink but this airplane doesn't have it right? Wrong, we found a procedure in the flight manual for using datalink and we followed it and we got our clearance that way. I've never experienced anything quite like it in 18 years. I am recently out of training. Our international training consisted of one day where we did a mini simulated leg to Hawaii. (1295260, 2015)

Other issues identified in ASRS reports involving DCL describe issues that are generalizable to all CPDLC clearances. One of these issues is the pilots' trust in the FMS ability to load the clearance (for example, with the use of the LOAD prompt). Some pilots who were accustomed to manually entering the clearance were reluctant to use automation to load the clearance (such as the LOAD prompt), even though it can reduce the data entry required, in general. As discussed in the DCIT, the mistrust of the LOAD prompt has resulted in errors incurred in the manual entry of the clearance. Within this data set, there were two events in which the pilot thought that the loaded route was incorrect and then manually entered what they thought the route should be:

- "We printed the message and selected the load prompt on the FMC [Flight Management Computer]. We compared the printed message with the FMC, but failed to notice that 41N30 and FATMO were deleted. Upon accepting the message and executing the FMC, the aircraft immediately turned direct to AMAKR. After a short discussion with the other pilot we heading selected back to the original course towards 41N30, then rebuilt our FMC Legs Page to 41N30 FATMO AMAKR BDEGA2 arrival. We called SFO ARINC [the radio operator] on HF to clarify our clearance, ARINC said they would ask SFO Center." The response from ATC was that "FOR TRAFFIC. I NEEDED YOU DIRECT AMAKR". (1482248, 2017)

- "In retrospect I believe that I had deleted the first part of our route (the revised segment) while leaving the original segment in the FMS" but then incorrectly thinks that, "the safest course of action is to NOT to uplink the revised route, but instead print it, enter it manually, and then "clean up" (delete) the "old" waypoints, and THEN check the entire route against the revised printout and Jepp plate". (1576926, 2018)

This line of thought is does not consider two important points. First, manual entry is likely to result in more errors than the use of the LOAD prompt, on most aircraft. Second, the printer is not certified to present a true representation of the clearance. Pilots are to verify the entered clearance against the display certified for this purpose.

From 2016 on, the majority of the ASRS reports involving DCLs describe errors involving a SID. DCLs that contain a SID introduce an added layer of complexity due to the fact that SIDs need to be manually entered, along with any runway transition, even when the rest of the route is loadable with a LOAD prompt and even when the SID has not changed from the previous clearance. Several reports reveal a lack of training in this area:

- In one case, the pilot seemed surprised that, “When the new SID was loaded manually, the transition dropped out.” (1382538, 2016)
- Another error occurred when, “after a CPDLC reroute was loaded, no runway transition was selected and a track deviation occurred.” (1453392, 2017)
- “I know it is a documented problem that SIDs and transitions on amended clearances do not load with the rest of the clearance, but in this case the SID and transition were the same in both clearances and we had already loaded and briefed the SID”. (1448842, 2017) *Note that the SID and transition need to be re-entered even when they have not changed from the previous clearance.*

In the following excerpt, the author opines that the requirement to perform steps that seem logically unnecessary can lead to pilot error:

- “…when selecting the “load new route” selection, it often drops out any loaded SID, and the corresponding legs on the SID. This is often unnecessary because the routes are exactly the same. This unnecessary step can lead to errors in lateral track and altitude deviations if they go unnoticed. I realize the importance of thoroughly reviewing all of the pages of the CPDLC and reviewing the loaded route.” 1588478 (2018)

Conversely, “cleared as filed” does not mean that the SID has not changed:

- Revision “stated cleared as filed, but as one went to the next page it stated the amended route to the original STAAV 6 SID. Both the First Officer (FO) and I failed to catch this change and flew the TRALR 6 SID”. (1386373, 2016)

It is important to note that this type of error was particularly prevalent in the initial implementation of data-linked revisions of the initial departure clearance and decreased over time. There were other reports, however, in which the pilots reported following the correct procedure but still encountered problems:

- CLEARED TO RBV VIA ROUTE CLEARANCE DIRECT TO SWANN N3909.0W0761 DIRECT BROSS N3911.4W0755 J42 RBV N4012.1W07429. +LOAD NEW RTE TO RBV+ AFTER RBV CLEARED TO ZZZZ AS FILED, JCOBY3.SWANN, CLIMB VIA SID, EXPECT FL310 10 MIN AFT DP, DP FRQ SEE SID. FO (First Officer) and myself reviewed the revised clearance, accepted it and he loaded it into the FMC via the LOAD FMC prompt. He then added JCOBY3.SWANN departure into the FMC. We reviewed the FMC to see that it followed the revised clearance…. As we continued to climb toward SWANN (probably around 15000 ft), Dulles Departure asked where we were heading and FO replied direct SWANN. ATC then gave us a heading to the right and said we were supposed to be on the published departure. ..ATC admitted that it was confusing and many aircrew have made the same mistake. His wording was "we have taken this to the national level" regarding this confusion. He said our deviation was no problem and gave us direct SWANN. (1404536, 2016)

- I failed to realize the EWR 4 departure was not loaded when we uploaded our new routing -- a pilot bulletin cautions about this very issue. The before takeoff checklist should have caught this error, but when I completed the checklist, I either saw what I wanted to see or the departure was there and somehow got dropped out later. (1695117, 2019)
- "Each time TERPZ 6.OTTTO was selected, FOXHL populated. We were both left confused as OTTTO only populated when the OTTTO transition was selected". (1539850, 2018)

One pilot expressed concern about not being able to verify the revised DCL:

- "We uploaded the new clearance using the load prompt, re-entered the departure runway, SID, arrival runway and STAR. However, the concern with the procedure is that there appears to be no way of verifying that the new uploaded departure is accurate". (1367183, 2016)

The following report submitted by an air traffic controller describes a local systemic error indicating that pilot error is not the only source of performance problems, "There was clearly confusion about the CPDLC [DCL] clearance upload. I listened to Clearance Delivery explain all details about the TRUKN2 SID with the SYRAH transition… the flight was showing direct SYRAH off of the airport. I have seen this before and we have had multiple pilot deviations due to this exact confusion." The controller goes on to suggest that FAA should ensure that "uploads work for the pilots". (1611071, 2019)

7.2 Failure to Detect One or More Differences in a Revised clearance

Several reports some of which involved DCL, describe the more pervasive error of pilots not noticing the difference between the clearance just received and the one they had already entered into the FMS:

- Pilot missed the different squawk code in the new clearance. (1781968, 2021)
- Crew received a revised clearance but did not see any differences between the clearance and what was already loaded in the FMS. They did not load the revision, despite the LOAD prompt. (1215694, 2014)
- There was an amendment of the [SID] to fly the HOLTZ 1 transition. We loaded that to the CDU [Control Display Unit] with the clearance prompt, then accepted the clearance. However there was no change to our filed route other than the [SID] HOLTZ1 vs. LOOP8. Enroute ATC asked if we were proceeding on course to PKE. We advised no, we were proceeding to DAG as filed. ATC

then gave us a vector and a new route. Apparently ATC had us on a completely different route than we had on the [flight plan]. This was not given to us from CPDLC. The only change shown was the [SID]. (1372189, 2016)

- Pilot didn't notice difference between revision and filed route and erroneously 'corrected' what was loaded with the load prompt. (1385776, 2016)
- "…we got Release 2, which we did not notice had different routing after ZALEA". (1518068, 2018)
- "The route looked familiar and I didn't notice the route change… The ability to print CPDLC on the ACARS would have trapped my error." (1765957, 2020)

7.3 Subtle Differences in Revised Clearances

Small differences between clearances are more difficult to detect than large differences. When clearances are nearly identical, the pilot may mistakenly believe that the clearance they just received is the same as the one already entered into the FMS. The following two reports exemplify this vulnerability, even when both pilots examine the clearance:

- "Both of us missed …a subtle waypoint change after N4940W from N4950W to N4850W." (1611105, 2019)
- The actual printout was "ZZZZA3. ZZZZZ", which means the ZZZZZ transition with the "dot" in between. We missed that dot. We both assumed the [DCL] clearance was direct from ZZZZA to ZZZZZ. (1778699, 2020)

Even when proper procedures are followed, both pilots can miss a small difference between the original and revised clearance, as demonstrated by this report from en route operations:

- "We checked and found that we still had our originally filed points of 50N030W and 50N020W in the FMC and not the cleared points issued to us of 51N030W and 51N020W. We changed the points and sent the info to dispatch. The leg we were on (to 51N040W) was correct so a Gross Navigation Error didn't happen, but we unintentionally set ourselves up for one. I don't know if the Gander Radio operator couldn't actually read the report or if that was a tactful way of saying "Check your planned flight route because what I see doesn't match." The most ironic thing about this almost-incident was that the Captain and I had quite literally just finished re-reading the Atlantic oceanic route clearance procedures in the FOM [Flight Operations Manual]. In spite of that, we still managed to miss digit changes on two points! We apparently saw-and/or-read what we expected to see instead of what was actually there". (1241013, 2015)

One report identified a factor that could contribute to not noticing a difference between a newly received message and a previous clearance:

- "Too often now, we receive a 'load new route' clearance when it is the exact same route as is filed. Then the new route and old cleared route are on two separate pages of the CPDLC. I think this can cause confusion and omissions". (1588478, 2018)

There are no data that identify how often pilots receive a 'repeat' clearance in actual operations, but anecdotally pilots report that it 'happens, but it's rare' (G. McMullin, personal communication, 2021).

7.4 Wishful Thinking

Several MORs identified cases where pilots read what they expected, or hoped, to see, rather than the actual clearance. The following two ASRS reports mirror this vulnerability:

- We were flying our first trip using CPDLC (Controller Pilot Datalink Communications). …We sent a request for FL430. ATC replied unable due to traffic. [Later] we received the message "standby your traffic is climbing." [A few minutes later] we received the message "your traffic is moving." Shortly after receiving [that] message we received a message that both I and my First Officer interpreted as a clearance to climb to FL430. We initiated a climb rate of approximately 300 fpm [feet per minute]. Passing approximately 41,800 feet we received a message to descend to maintain FL410. We immediately initiated a descent and returned to FL410. [We then] received the message "maintain FL410. Possible higher once traffic moves." [Shortly thereafter] we received the message "climb to and maintain FL430." Both myself and my First Officer are perplexed with this series of events. We both saw a message which we both interpreted as a climb clearance. We both saw a message instructing us to descend to FL410. Neither of these two messages are stored in the message log. (1613422, 2019)
- "This was simply an altitude deviation due to wishful thinking because of our immediate circumstance. The Captain and I both thought we saw a clearance to FL330 because that's what we wanted to see. At the time we were in heavy turbulence… we decided to request a higher altitude from ATC. They denied our 34,000 ft. request so we immediately sent another request for 33,000 ft. The Captain and I both thought we saw a clearance to 33,000 ft. At the time we were in very turbulent air. After we started the climb I checked CPDLC to make sure report was armed. When I couldn't find the report prompt I realized our mistake and informed the Captain. By that time we received a call from ATC…". (1689558, 2019)

7.5 Messages Received in Quick Succession

A short interval between CPDLC messages has been shown to increase the chances of pilot error both in executing a CPDLC message (by failing to implement part of the clearance) and missing a voice transmission as well as significantly lengthening the pilot response time and clearance entry times for a data link message (Dunbar et al., 2001). The following report from US domestic en route airspace exemplified this:

- “It was a little overwhelming with all of the ATC messages we were receiving on the CPDLC… We had been receiving one CPDLC message (from Kansas City [Air Route Traffic Control Center]) every five to ten seconds for over a minute. Captain was PF (Pilot Flying) and also answering all CPDLC messages. As PM (Pilot Monitoring), it was difficult to read all messages and keep up with PF as he zipped through the messages trying to comply”. (1587588, 2018)

7.6 Message Complexity

In controller-pilot voice communications, complex messages are known to be more error prone than simple messages. The following reports identify the need for CPDLC clearances to be as simple as possible, especially in response to a pilot request:

- “I suggest that ATC not give a route change without an advisory warning. *And to not give a route change when the previous request was an altitude change only*. …New York's practice of issuing multiple changes (i.e., temporary FL change and a route change more than one thousand miles distant) in one CPDLC communication is an unsafe practice that lends itself to many misinterpretations and errors.” Similarly, the narrative for the other pilot involved in this event also suggests that complex clearances can be problematic: “When sending amended or revised CPDLC clearances, send only one (1 item) per message to acknowledge. I.e. altitude, speed, or route/fixes, only one per message, not multiple as this form of communication is very simplistic and doesn't lend well to complex clearances”. (1231548, 2015)
- “I think the combination of both a climb and route change clearance combined into one ATC message causes the slow response time in the computers” “the message stated “ROUTE AND ALTITUDE CHANGE,” but still saw no routing. [Pilot Monitoring] noted that on page 2 of the message we saw the "ARM" for the altitude reporting and that no "LOAD" prompt appeared. We exited out and re-entered the received messages and noted that after about a minute, a "LOAD" prompt appeared. There was still no routing, just a LOAD prompt”. (1663375, 2019)
- Both pilots missed the cancellation of the block altitude clearance. It was imbedded in the re-route due to weather. Pilot suggested that two separate messages would have been more clear. (1767811, 2020)

7.7 Clearances that Cannot be Complied with Due to Aircraft Performance

Aircraft performance limitations need to be assessed before pilot “WILCOs” the clearance.

- The flightcrew requested a climb to FL390 via CPDLC for fuel efficiency and a smoother ride. While the exact clearance sent is uncertain, it was most likely CLIMB to FL390, CLIMB to reach FL390 by position. The flight crew discussed the clearance and monitored the position page to track the progress. "Seeing that we had a 6-minute window, more or less, I opened the vertical speed window on the FMS and initiated a 400 feet/minute accent, which would produce a level-off, easily, within the required time-frame and not noticeable for the passengers. Instead of being concerned with the exact plotting of the required level-by clearance, we both agreed that it was very clearly, a level-by-[fix] clearance. Looking at the prog page/position on the FMC, I initiated a level-off at FL390 about 5 minutes later, or 19.5 degrees, within the requested window. We had armed the CPDLC to report the level FL automatically, which we verified was sent properly…. A definite surprise having a call regarding our non-compliance! On a similar flight, the next sequence after my submission of the text above, I did a test of aircraft performance in an identical time scenario. With a normal autopilot pitch up and normal power/throttle advancement, plus a no wind condition (we compared no tail wind potential and then subtract for a strong tailwind/ground speed increase). With a 90 knot direct crosswind, we started a time hack and it took 1 minute and 22 seconds to cover the distance from [our current position]. I figured that without 95 knot direct tailwind, we would have had to be level in 1 minute, 6 seconds. This type of clearance is normally received with - be level by - 3 degrees, which gives a lot of time to climb. Since this was a "stand on your tail" clearance, we both were lured in to thinking it was a degree and a half to climb, not 3/4 of a degree to climb. Our fault, no doubt, as we should have rejected it". (1357038, 2016)

- "We complied with SID and crossed RUGBB at 12,000 feet. But we did not comply with the CPDLC instruction to cross JHAWK at 12,000 feet. Looking back, there is no way we could have crossed JHAWK at 12,000 feet regardless". (1587588, 2018)

7.8 Pilot-ATC-Dispatch Coordination

For air carrier operations, the company dispatch, ATC, and pilot need to have a common understanding of what routes the aircraft can accept:

- "For months, basic 757s have not been allowed to do RNAV [Area Navigation]. Dispatch files a non RNAV SID. We file correctly, they change it. We then told them we can't do it, they change it back. Tower then tells us to fly something we told them TWICE we cannot do". (1456356, 2017)
- The planned route to avoid ATC Zero airspace became unavailable and ATC provided a new route which resulted in the flight being in a non-radar environment. First Officer stated that they were later informed by company that they were not allowed to accept such a route. (1782749, 2021)
- Dispatcher planned a flight through HF required airspace on a non-HF equipped aircraft. (1782619, 2021)

7.9 'Oceanic Clearance' is Not a Clearance

To enter oceanic airspace, the pilot must submit a Request for Clearance (RCL). The RCL can be submitted via data link and must include the Oceanic Entry Point (OEP, the waypoint at which the aircraft first enters the oceanic control area), Estimated Time of Arrival (ETA) for the OEP, requested speed (Mach number) and requested flight level. In response, ATC sends an 'oceanic clearance'. Two of the reports describe the error of pilots interpreting the flight level component of this "oceanic clearance" as a clearance, when in fact, it is more of an 'expect' message. In one case, the clearance "FM ELSIR/1136 MNTN FL350" was interpreted as an immediate climb to FL350 (1597062, 2018). The message is an abbreviation from ELSIR (the oceanic entry point, which you are expected to cross at 1136) maintain Flight Level 350'. However, the flight level contained in the 'oceanic clearance' is not a clearance to climb, either immediately or upon crossing the entry point. In fact, the pilot is not cleared to climb to the specified altitude until instructed to do so. A report of a similar incident is more detailed:

- "Captain didn't wait for clearance to climb given the oceanic clearance. 'FM OGIVO/1619 MNTN M084 F350' After ADEMA and in XX07 Airspace the Captain climbed to FL350 just prior to OGIVO per the Oceanic Clearance. They then received a CPDLC to "climb and maintain FL350, report leaving FL340 and report reaching FL350". They sent a CPDLC that they were level at FL350. I felt the Captain should have gotten a clearance from Murmansk (current controlling authority) to climb to FL350. This is the second time in as many months I've seen this. And my second [report] on this issue. I am looking for direction from the [report] review committee and/or the FAA's or controlling authorities interpretation on this issue as to the requirement of getting a climb clearance to the higher cleared altitude of the oceanic clearance, as well as what is required if you are not yet at your Oceanic Clearance Cleared Altitude and you reach the Oceanic Coast out fix. (1309772, 2015)

Changing flight levels upon the receipt of the oceanic clearance has also occurred many times in Canadian domestic NAT airspace and is slated for removal in 2023 for all NAT sites (Shelley Bailey, NAV Canada, personal communication, 2022). The FAA has already discontinued its use.

7.10 The Need for Timely Resolution of Requests for Weather Deviations

The vast experience with CPDLC comes from the oceanic environment. One issue specific to the oceanic environment, but relevant to clearance negotiation is the need for timely resolution of requests. As seen in the MORs, there were several reports of pilots deviating from a clearance to avoid hazardous weather. These events exemplify the need for timely responses from ATC to requests for weather deviations. Between 2011 and 2019, seven reports described instances of pilots requesting a weather deviation and then maneuvering without authorization (1285660, 1620468, 1581840, 1570879, 1168184, 1157377, & 964149). In some cases, the pilot received an UNABLE response from ATC, while in other cases, no response was received. In each case, the pilot maneuvered on the authority of pilot-in-command to preserve the safety of the flight but failed to follow the prescribed procedure.

7.11 Display Issues

One advantage of ASRS reports is that they contain pilot insight into the factors that contributed to the error. One limitation of pilot reports is that there is no way to know exactly what the clearance was or how it was displayed to the pilot. Several reports contain comments from pilots that the way in which the message was displayed contributed to the error:

- "We received a response in large lettering, "UNABLE REQUESTED ALTITUDE DUE TO TRAFFIC," followed by small lettering, "climb to and maintain FL350." We missed the clearance to climb to FL350 and maintained FL340". (1683293, 2019)
- "…Since the 'at N20E160' is not located next to the rest of the reroute, it is very easy to miss. Having it separated by even a few lines makes it very easy to miss when verifying the correct clearance is loaded and executed." In this case, both pilots independently viewed the message and made the same mistake. (1618371, 2019)
- "Receiving the ATC clearance over the Air Traffic Control Data Link system without the ability to print the clearance and crosscheck with the FMS (Flight Management System) & SID is cumbersome. The clearance is displayed on a small screen, often times with multiple pages for the clearance. When reviewing the clearance, and paging through each page can cause the pilot to miss the full clearance. In this case, we both separately reviewed the clearance on the CDU and did not see the altitude restriction of 4,000". (1684522, 2019)
- "Cleared to [exit point] via route clearance" to which I thought it was our normal, but differently stated, 'verify route' message. I said accept, and the international relief officer hit "load" (I thought it was an "accept" prompt) and execute before I noticed it was a load button and I never saw the execute action it was so quickly done. Then we got 5 different CPDLC messages, some of them repeats, about verifying route etc. [for the next 10 minutes]. It was somewhat confusing so many messages. At no time, did any of the messages say there was a change to our clearance. …It was only going through the log of CPDLC we found the error. On the [earlier CPDLC] message, on the green screen, [it] doesn't say what the points are, or that this is a change, but when you print it out, you see the points and because it was executed so quickly (again, I thought it was an "accept"), I didn't realize it was loading these new points. (1673768, 2019)
- Pilots saw CLEARED TO [position] via.. on the printout, but on the FMC screen it looked like they were cleared direct to [position] "We then looked at our Printed clearance, and saw on that, cleared to ILC via SYRAH Q128 JESICA Oak8 this is a revised clearance. This does NOT show up on the FMC screen!!!!! We took photo of clearance as proof it wasn't there on the FMC. This format on the FMC is a problem. 1371169 (2016).

It should be noted while it is difficult to determine what was displayed to the pilot on the display intended for that purpose, an ICAO NAT OPS Bulletin, NAT Data Link Special Emphasis notes that the uplink "CLEARED TO (position) VIA (route clearance)" may not show the "VIA ROUTE CLEARANCE" portion until it is loaded. (ICAO, SPG, 2021). This error in which a pilot interpreted "Cleared to POSITION via route clearance" as direct to position continued to be reported in a total of four ASRS reports, the other three of which were reported in 2020 (1773600, 1773597, 1773600). Although there were no MORs in this data set involving this error, the DCIT has identified it as the most commonly observed pilot error associated with en route CPDLC clearances (as of January 2022).

- Two reports suggested that CPDLC should display the full route clearance if any revision has occurred. One noted that, "Just as clearance delivery would read the full route clearance if a route change has occurred or PDC would clearly show the revised segment, CPDLC should do the same. And CPDLC should clearly state there is a revised route" (1383341, 2016). Another stated, "I think if the CPDLC had displayed the full route it would have made this a non-issue… Also, a better briefing of both the departure SID and arrival STAR (since it was a short flight) may have highlighted the error". (1369842, 2016)

It should be noted that it is not possible to change the presentation format of the clearance in FANS, on the FMS display. Also, while the procedures to display the full route differ among aircraft, each FANS aircraft has this capability. Finally, a thorough briefing of the route, including SIDs and STARs is standard operating procedure, with or without CPDLC. While identified as a display issue by pilots, proper training could help to mitigate these events. *Pilots who operate aircraft on which it is necessary to LOAD the clearance before being able to see the entire clearance should be trained to do so.*

7.12 The Importance of Flightcrew Training and Procedures

The importance of training on the implementation of CPDLC (both for en route operations and for departure clearances) was also represented in the reports. One report described an incident in which the pilot did not understand the basic procedure that the amended clearance to FL360 cancelled his previous two climb clearances (1386341, 2016). In a report from 2020, a pilot familiar with CPDLC was surprised to see a CPDLC clearance in the en route environment:

- "ATC on CPDLC (Controller Pilot Datalink Communications) gave us a climb and maintain FL 360 without an ATC controller assigning us a clearance via radio. I don't remember seeing or reading if B737's can legally accept this type clearance. Why is ATC giving us CPDLC altitude clearances? We're not ETOPS [Extended-range Twin-engine Operational Performance Standards] over Washington DC! Now they're giving us reroutes via CPDLC. I don't know if we can accept these as well. I have talked to many pilots and the Assistant Chief Pilot and no one has an answer to my situation". (1767444, 2020)

One early report describes the first officer accepting the clearance without conferring with the Captain and then realizing that this was a mistake. A later report confirms the unnecessary vulnerability of a single pilot processing the clearance when two pilots are present:

- "I should have discussed the clearance with the Captain prior to accepting/rejecting it via CPDLC". (1352613, 2016)

- “I had the expectation that the ATC route clearance had no changes, so I verbally briefed the route “as filed” and failed to visual[ly] review the CPDLC a second time for any possible revisions…. I immediately pulled up out CPDLC clearance and we both realized for the first time that we had received, missed and failed to load a revised ATC route clearance prior to takeoff. We then loaded the amended clearance and continued the flight without incident. (1644396, 2019)

To guard against the human vulnerability to see what one expects to see, the procedure recommended in the ICAO *GOLD* Manual (Doc 10037, 2017) is for each pilot to independently and silently read the clearance before discussing it with the other pilot. If one pilot reads it aloud before the other pilot sees it, the second pilot is predisposed to see what was heard and is not likely to detect small differences between the two.

- “Cleared to ZZZ APRT LGA5 EXCEPT TURN LEFT HDG 360 FOR RV THEN AS FILED”. When I received and acknowledged the clearance, I read it to the Captain stating EXPECT TURN TO 360 instead of EXCEPT …. the Captain read the CPDLC and acknowledged what we briefed. (1702288, 2019)

It should be noted that, from a human factors standpoint, the use of highly confusable words, such as ‘expect’ and ‘except’ in CPDLC clearances is problematic and should be minimized.

It is equally critical to verify the route entered into the FMS against the clearance in its entirety, although not all pilots seem to view this as important:

- “Obviously, had I checked each individual fix, I would have caught the problem”. (1572982, 2018)
- “I checked the MOD as I stated, but I did not recheck the whole route, why would I….The Pilot in Command was inside FBO doing PIC duties. We did not check route together. But that is not unusual”. (1590376, 2018)

7.13 Recommendations from Flightcrews

Several pilots suggested changing the ways in which the CPDLC clearances are displayed to them. However, this is not possible with current equipage. Pilots also expressed a desire to be able to print the CPDLC clearance, but the printers are not currently certified to provide a true representation of the clearance. The best recommendation came from a report describing a clearance negotiation that resulted in flightcrew error. In this case, the flightcrew requested an altitude change, received a route revision, and missed the altitude revision. The pilot stated, “I suggest that ATC not give a … route change when the previous request was an altitude change only. The co-pilot similarly suggested, “When sending amended or revised CPDLC clearances, send only one (1 item) per message to acknowledge. i.e. altitude, speed, or route/fixes, only one per message, not multiple as this form of communication is very simplistic and doesn’t lend well to complex clearances.” (1231548, 2015). This is a sound recommendation that is reflected in ICAO guidance; altitude requests should be responded to directly. Similarly, clearances should be as simple as possible to minimize error.

8. Guidance for Flightcrews on Clearance Negotiations

Guidance on clearance negotiation needs to be specific to the aviation environment in which it will be used. The CPDLC messages and procedures that pilots can use are different in the US oceanic and domestic en route environment than in the oceanic environment.

8.1 Clearance Negotiations in the Domestic En Route Environment

The Pilot Handbook - U.S. Domestic Controller/Pilot Datalink Communication (CPDLC) Operations describes the clearance negotiations possible in today's en route environment (Harris, 2021). The flightcrew may request a clearance to proceed direct to a position on the current route (using REQUEST DIRECT TO [position]) and request a change in altitude (using REQUEST [altitude]). Altitude requests in the en route environment are limited to single altitudes; block altitudes are not currently supported. The use of any other REQUEST message available in FANS will result in an automatic error message being sent to the aircraft. An automatic message of "respond UNABLE" and "DOWNLINK MESSAGE NOT SUPPORTED" will also be received if the flightcrew requests both an altitude change and a REQUEST DIRECT in the same transmission. It is important for flightcrews to be aware of the different capabilities in the different environments.

The NAT Oceanic Errors Safety Bulletin Ops Errors Safety Bulletin states that the flightcrew should revert to voice communications as needed to "clarify the meaning or the intent of any unexpected, inappropriate or ambiguous CPDLC message" (ICAO 2021, p.7). The Pilot Handbook stresses repeatedly that the flightcrew should contact ATC by voice if the CPDLC message is 'unclear or conflicting' (Harris, 2021, p.4).

8.2 Clearance Negotiations in the Oceanic Environment

ICAO documents offer globally harmonized guidance on air traffic and flight crew procedures. The *GOLD Manual* (ICAO Doc 10037, 2017) is the authoritative source of guidance for air traffic controllers and pilots in the use of controller-pilot data link communications in oceanic airspace. It contains best practices for pilots and controller to minimize error and specific guidance on clearance negotiation. The *GOLD Manual* originated as a regional guidance document before it was revised and published as a global manual. While the document has since been updated, the latest update has not yet been published (the expected publication date is late 2022). Material that will appear in the future revision is referenced here as 'ICAO Doc 10037, in press'.

8.2.1 General Guidance for Flightcrews on CPDLC

The *GOLD Manual* contains several general recommendations for flightcrews to minimize errors associated with CPDLC clearances:

Use of standard messages
The flightcrew should use standard downlink message elements to compose and send clearance requests. This means that the flightcrew should select the preformatted messages in the system rather than construct them using free text.

Use of standard phraseology and abbreviations
When no appropriate message element exists, the flightcrew should use standard ICAO phraseology and abbreviations to compose the free text message.

Use of appropriate flight deck display
Flight deck printers are not certified for the purpose of displaying CPDLC messages. The *GOLD Manual* reminds flightcrews that all messages should be reviewed using the flight deck display certified for this purpose, since "printers may not produce an exact copy of the displayed CPDLC messages with required reliability" (Section 3.3.1 5, ICAO Doc 10037, in press).

Independently and silently read and confer
Identified by many as the "GOLD procedure", the *GOLD Manual* specifies that "Each flight crew member (e.g., pilot flying and pilot monitoring) should individually review each CPDLC uplink message prior to responding to and/or executing any clearance, and individually review each CPDLC downlink message prior to transmission. Reading a message individually is a key element to ensuring that each flight crew member does not infer any preconceived intent different from what is intended or appropriate. Reading the message aloud would bias the other flight crew member and could lead to the error of 'reading' what was read aloud as opposed to what was actually displayed" (ICAO Doc 10037, 2017, p. 4-2). Edition 2 refines this guidance to read: "Both pilots should individually and silently read each CPDLC uplink message from the flight deck displays (including the uplink time stamp) and discuss prior to responding to and/or executing any clearance. Reading the message aloud would bias the other flight crew member and could lead to the error of 'reading' what was read aloud as opposed to what was actually displayed. The procedure of reading a message individually and then conferring is critical to preventing errors due to pilot expectations, particularly with complex or conditional clearances." (Section 3.3.1.3, ICAO Doc 10037, in press). Both versions of the *GOLD Manual* also stress the importance of each flightcrew member individually reviewing any CPDLC downlink message before being sent.

The GOLD procedure is the best safety net for errors associated with conditional clearances. As previously discussed, ICAO has long recognized the increased propensity for communication errors associated with conditional clearances. Both the current edition of the *GOLD Manual* and Edition 2 (in press) state that, "While conditional clearances add to the operational efficiency of the airspace, they have been associated with a large number of operational errors." (ICAO Doc 10037, 2017, p. 4-10; and

Section 3.3.6.1, ICAO Doc 10037, in press.) Edition 2 also advises controllers that they, "should only use conditional clearances after determining that the operational efficiency outweighs the risk of a missed condition on the clearance" (Section 3.3.6.2, ICAO Doc 10037, in press).

The GOLD procedure can also help to guard against interpreting an EXPECT message as a clearance. While EXPECT message elements can be useful for planning purposes, they can also lead to errors when pilots mistakenly interpret one as a clearance. The *GOLD Manual* identifies messages contained in the FANS 1/A CPDLC message set that should no longer be used (such as EXPECT [altitude] AT [time]) because of potential misinterpretation and suggests that instead, controllers issue messages that cannot be construed as a clearance, such as EXPECT HIGHER at [time]. The *GOLD Manual* also reminds flightcrews that they should not act on an EXPECT message as if it was a clearance. (An exception is when the EXPECT message is received as part of an ATC departure clearance where compliance may constitute part of the radio communication failure procedure).

8.3 Clearance Negotiation

All negotiations begin with a request. It is a common practice for pilots to request a change of altitude to avoid turbulence or improve aircraft performance. As the *GOLD Manual* specifies, if a controller cannot issue an altitude clearance that has been requested by the flight crew, the controller should reply UNABLE to deny the request and include any reason for the rejection (such as DUE TO TRAFFIC). This guidance represents a 'lessons learned' from incidents in which controllers responded to an altitude request only with a clearance to a different altitude that they could accommodate. Too often, in these cases, the pilots flew to the altitude that was requested, rather than the altitude in the clearance. The reply of UNABLE serves to decrease the chances that the pilot will mistake the controller's response as a clearance to the requested altitude. The addition of the reason as to why the request cannot be granted, fortifies the UNABLE message, but still has not prevented pilots from seeing the altitude clearance that they requested.

The *GOLD Manual* further specifies that, in the case in which the requested altitude cannot be issued, the controller may subsequently uplink an alternative clearance, such as an intermediate level or climb to begin at a future time in a separate CPDLC message. This is only to be done if the controller has reason to believe that the clearance can be accepted by the flightcrew. The guidance states that, any alternative clearance, such as an intermediate level or a climb in a conditional clearance, should be subsequently uplinked in a separate CPDLC message (ICAO Doc 10037, 2017, p. 3-18). This guidance has evolved, however, to state that the alternative clearance may be sent in the same message as the UNABLE response (annotated with the reason) to the request (Section 3.3.10.1.1, ICAO Doc 10037, in press): "If the controller deems that the flight crew is likely to accept an alternative clearance (intermediate level or deferred climb), the controller may uplink the clearance in the same message or in a separate CPDLC message."

The examples below were adapted from the ICAO *GOLD Manual* (Doc 10037, in press). In both examples, the flightcrew has requested a higher altitude of FL370 and the controller is unable to grant the requested altitude due to traffic. In the first example, the controller offers an intermediate altitude in the same message:

Flightcrew	REQUEST CLIMB TO FL370
Controller	UNABLE DUE TO TRAFFIC CLIMB TO FL360
Flightcrew	WILCO or UNABLE

In the next example, the controller issues a clearance to an intermediate altitude in a subsequent transmission.

Flightcrew	REQUEST CLIMB TO FL370
Controller	UNABLE DUE TO OPPOSITE DIRECTION TRAFFIC
Controller	CLIMB TO FL350. REPORT MAINTAINING FL350
Flightcrew	WILCO or UNABLE

If, however, the controller is uncertain as to whether the flightcrew would be able accept an alternative clearance, the controller should negotiate the clearance prior to issuing it. The *GOLD Manual* states that the controller "should negotiate the clearance with the flight crew" (p. 3-18) prior to issuing any alternative clearance that the flightcrew might not be able to accept. While the current version has limited guidance on clearance negotiation, this is remedied in *GOLD Manual* Edition 2 (in press). The increased operational importance of clearance negotiation is also reflected in the recent change to the title of the relevant section; "Offering alternative clearances to requests" (ICAO Doc 10037, 2017) was changed to "Clearance negotiation" (Section 3.3.10, ICAO Doc 10037, in press).

When negotiating a higher or lower altitude, the controller should use the appropriate standard message to inquire when the pilot can accept a given altitude – "WHEN CAN YOU ACCEPT [level]". In response, the flightcrew should compose the response from those preformatted in the system for that specific purpose, rather than composing a response using free text. These preformatted messages on the flight deck are prepopulated so that only the variables need to be inserted after the message is selected. For example, upon receipt of the message, "WHEN CAN YOU ACCEPT FL350", the flightcrew of an equipped aircraft will be presented with the preformatted response "WE CAN ACCEPT FL350 AT [time]". The time is the only variable and would be selected by the flightcrew. Under no circumstances should pilots respond with a free text message (such as 'now') and proceed to the stated altitude without a subsequent clearance to that altitude. Note that following this procedure could have prevented several of the errors found in this analysis.

In the following example, the aircraft is maintaining FL330. The controller is unable to issue the requested clearance, and queries whether the aircraft can accept a flight level that is higher than requested.

Flightcrew	REQUEST CLIMB TO FL370
Controller	UNABLE DUE TO OPPOSITE DIRECTION TRAFFIC
Controller	WHEN CAN YOU ACCEPT FL390
Flightcrew	WE CAN ACCEPT FL390 AT TIME 2200

FNote that, in this example, the flightcrew cannot begin the climb to FL390 until the clearance is received, even if the current time is 2200. Controllers might also query the flighcrew CAN YOU ACCEPT (level) AT TIME (time) or CAN YOU ACCEPT (level) AT (position). Most FMCs have the capability to provide the flightcrew with an estimate (in time and/or space) as to when a given altitude can be achieved. However, these estimates are only as accurate as the information (particularly wind information) used to compute them. The *GOLD Manual* emphasizes this difference between negotiation messages and a clearance. "The flight crew should recognize that the negotiation referenced in 3.3.10.1 and 3.3.10.2 does not constitute a clearance (even when the option under negotiation could be accepted immediately)" (3.3.10.3, ICAO Doc 10037, in press). The flightcrew is always required to wait until the actual clearance is received before a maneuvering the aircraft.

8.4 Multiple clearance requests

The *GOLD Manual* states that the flightcrew should avoid sending multiple clearance requests in a single downlink message. For example, the flightcrew should send separate downlink messages for REQUEST CLIMB TO (level) and REQUEST DIRECT TO (position) unless there is an operational need to combine them in a single message; in this case, the flightcrew does not want to climb unless they can proceed direct to the stated position.

If the controller receives multiple clearance requests in a single message and can approve all clearance requests, the controller is required to respond in a single message that includes the appropriate clearance for each request in the message (ICAO Doc 4444, 14.3.2.3.6). In the following example, the flightcrew requests a climb to FL370 and a clearance to proceed direct to the position TONTO. (The flightcrew should only make such a request if the desire is to climb only if they can proceed direct to TONTO.)

Flightcrew	REQUEST CLIMB TO FL370 REQUEST DIRECT TO TONTO
Controller	CLIMB TO FL370 PROCEED DIRECT TO TONTO

If the controller receives multiple clearance requests in a single message and cannot approve all the clearance request elements, the controller is required to send, in a single message, UNABLE, which applies to all elements of the original message (ICAO Doc 4444, 14.3.2.2.5). The controller may, but is not required to, include a reason for the rejection (such as "DUE TO CROSSING TRAFFIC").

If the requested altitude is only available if the aircraft is able to cross a position at a specific altitude, the controller would issue the mutually dependent clearances in a single message. In the following example, the requested altitude is FL350. The controller can only issue FL350 if the aircraft crosses the position TAFFY at or above FL310. In this case, the controller would issue the mutually dependent clearances as follows:

Controller	CLIMB TO FL350 CROSS TAFFY AT OR ABOVE FL310

Note that it has long been the case that the flightcrew should only respond with WILCO if all the clearances in the entire message can be complied with. If the flightcrew cannot comply with a portion of a multi-element message, the flightcrew should respond to the entire message with UNABLE.

We have seen that crews can become frustrated with the lengthy response time of ATC to such requests. We have also seen that a controller may need to take multiple actions before they can grant such requests. Any streamlining of these processes to be able to respond quicker to pilot requests will help realize the projected benefits of clearance negotiation. The *GOLD Manual* contains guidance for flightcrews who have not received a response to a non-urgent request message to change altitudes within what they perceive as a reasonable time. If the flightcrew has not received a response within the expected time, they should query the controller as to when a response can be expected either by voice or by using "WHEN CAN WE EXPECT [higher/lower]" (ICAO Doc 10037, 2017, p. 4-14). The controller then responds with "YOU CAN EXPECT [higher/lower] AT [time/position]" (ICAO Doc 10037, 2017, p. 3-10). Similarly, pilots are instructed to avoid the use of the message 'WHEN CAN WE EXPECT DESCENT /CLIMB TO (level)' and instead, use "WHEN CAN WE EXPECT HIGHER/LOWER LEVEL" (ICAO, Doc 10037, 2017, p. A-60). In no case should the flightcrew resend a request. There are several aspects to this procedure that are designed to minimize miscommunication. First, it precludes the pilot from repeating the request, thus opening another dialog that must be closed. Second, it precludes making a similar request (e.g., for an intervening altitude) that could create an additional opportunity for error. Most importantly, by specifying 'higher' or 'lower' rather than a specific altitude, it precludes the pilot interpreting it as a clearance. The phraseology used in the Baseline 2 (B2) message set has evolved from that in FANS to reflect this; messages to expect specific altitudes at specified times or positions have been deleted and replaced with messages to EXPECT HIGHER/LOWER.

8.5 Negotiation of 4D clearances

Dynamic TBO is described as "[using] advanced aircraft and ground automation to enable flight specific time-based solutions for reroutes and aircraft sequencing and advanced aircraft-based pairwise trajectory solutions. Information will be integrated and shared to further improve NAS operations" (FAA, *NextGen's Path to TBO*, 2018). It is scheduled for implementation in the U.S. in the 2026-2030 timeframe. The *GOLD Manual* Edition 2 (ICAO Doc 10037, in press) contains a description TBO that involves the exchange and synchronization of trajectory data between ground and aircraft systems, including the exchange of 4-dimensional clearances and intent information. This will enable the negotiation of 4D clearances and conformance monitoring that is more advanced than is in use today.

A TBO clearance, or 4D clearance, consists of constraints (i.e., lateral vertical, time and/or speed) issued by the ATC for conformance along the cleared route of flight on the 4D trajectory. Specifically, a 4D trajectory consists of:

- the lateral path consisting of route waypoints,

- the vertical path consisting of the predicted altitude (and vertical constraints, if any) at each of the waypoints forming the lateral path,
- the predicted speed (and speed constraints, if any) at each of the waypoints forming the lateral path, and
- the predicted time (and time constraints, if any) at each of the waypoints forming the lateral path and specified vertical points (such as Top of Descent).

High-level recommendations on clearances and procedures for negotiation in the TBO environment were developed regionally for Air Traffic Service Providers. They are summarized here and will be published in the *GOLD Manual* Edition 2 to facilitate the development of a global procedure (ICAO Doc 10037, in press). This guidance is expected to evolve as TBO operations mature.

Prior to the start of the flight, the 4D trajectory is negotiated and synchronized between the aircraft, the aircraft's operations center and air traffic control. The 4D route clearance is sent in two uplink messages. The 2D Route message is sent first, followed by Level uplink message. "This is because the 2D Route can be implemented immediately by the flight crew, whereas the FL is still subject to ATCO instruction. Moreover, displaying long message over several pages should be avoided because of display limitations in some current aircraft types." (Table 4-6, ICAO Doc 10037, in press). Any modification to the 4D route clearances would be coordinated between the aircraft and the air traffic control (and, if time permits, the operations center).

The procedures for TBO and 4D clearance negotiation will need to be carefully defined. They will need to consider the known risks associated with complex clearances and procedures and the need for these clearances and procedures to be compatible with the flight deck automation and published procedures (FAA, 2013, p. 228).

9. Summary and Future Directions

We have operationally defined complexity of CPDLC clearances as the sum of factors that contribute to pilot errors associated with those clearances. To that end, we have identified three different dimensions of complexity that contribute to pilot errors with CPDLC clearances: visual, cognitive, and technical.

The factors identified to date as contributing to the *visual and cognitive* complexity of a CPDLC clearance or those relayed by third-party voice are:

- Number of elements (pieces of information) in the transmission – the more information presented in a clearance, the higher the complexity of the CPDLC clearance.
- Number of lateral and vertical changes to a clearance in a single transmission (and whether the transmission contains only one type of clearance or both). When the clearance contains only vertical or only lateral changes, the transmission is considered to be less complex than a clearance that contains both vertical and lateral components.

- Whether the clearance contains a conditional component (e.g., AT [time] CLIMB TO [altitude]). The use of conditional clearances adds to the flexibility of the airspace but also adds to the complexity of the pilot's task and increases the opportunity for error. Pilots often miss the conditional portion of the clearance (e.g., AT [time]) and execute the clearance too soon.

Factors that contribute to the *technical* complexity of a CPDLC clearance are:

- Whether the clearance contains a conditional component. Conditional clearances also contribute to the technical complexity of a clearance in that, even when they are read correctly, there is a complexity to their execution. Conditional clearances that require the flightcrew to take an action in the future can be forgotten.

- Whether the clearance is loadable with a LOAD prompt or not, or contains a combination of loadable and non-loadable components. When the entire clearance is loadable with a LOAD prompt, it is less complex than the same clearance (i.e., all other factors being equal) that must be manually entered. However, when a loadable clearance is sent with components that must be manually entered (such as a SID), this adds to the complexity. Multiple errors have been observed in the addition and verification of the component of the clearance that required manual entry.

These dimensions interact in ways that are dependent on important features of the aircraft that cannot be characterized by the clearance alone and are not typically captured in MOR reports such as: the way in which the clearance is displayed in the aircraft, the automation support for loading the clearance into the FMS (i.e., the degree to which the clearance can be loaded into the FMS with the use of a LOAD prompt), and automation support for execution of the clearance, such as reminders of the time or position to execute a clearance. The following factors contribute to message complexity on the flight deck:

- Number of pages used to display the transmission (this will vary with the equipment) – the greater the number of pages needed to display the clearance on the flight deck, the higher the complexity of the CPDLC clearance.

- Clearances similar to, but different, from, what was requested by the pilot are more complex than clearances that are the same as the requested clearance. This is because the pilot has the expectation to see the clearance requested. Several errors involved pilots flying to the requested altitude rather than the one contained in the clearance.

- Revisions with small (difficult to notice) changes to the previous clearance are more complex, and subject to error, than revisions that contain a major change in the route. A common error associated with oceanic clearances is the flightcrew flying the flight plan instead of the clearance. While the MORs of these errors do not include information about the nature of the error, ASRS reports reveal that pilots often review the 'revised clearance' and fail to notice the differences between the revision and what they have already entered into the FMS, and as a result, do nothing.

These metrics of complexity need to be considered in research that should be conducted when the messages proposed to be used for clearance negotiation are identified. This research can inform the development of guidance for pilots and controllers on clearance negotiation with the CPDLC messages that are to be used in the process. In addition, the following are recommended:

- **Determine effectiveness of current error mitigation strategies.** The first logical step in identifying error mitigation strategies for future operations is to examine the effectiveness of the error mitigation strategies implemented in today's operations. As previously discussed, FAA is currently appending a free text message in domestic airspace (UM169) of the complete routing when issuing UM79 CLEARED TO (position) VIA (route clearance). There is an anecdotal report that this "seems to reduce errors", but the FAA collects no data on how effective this is in mitigating the errors (C. Collings, Data Link Users' Forum, September 13, 2021).
- **Continue to refine procedures for clearance negotiation.** The guidance on clearance negotiation contained in The *GOLD Manual* was written for the message set and procedures used in the today's oceanic environment. As capabilities evolve, both in the en route and oceanic environments, so will the need to refine guidance on clearance negotiation. This guidance will need to be tailored to the available message set and procedures that are specific to the airspace in which they will be used.
- **Continue to ensure that messages are developed and refined with human factors support.** The message set will change in the future as the Baseline 2 (B2) message set will be considerably different from the FANS message set. This message set continues to be refined to support future operations. Continued human factors support is required to help ensure that the flight deck and air traffic procedures and phraseology for clearance negotiation are developed in tandem in ways that seek to minimize human error.
- **Ensure continued data gathering and analysis of usage and associated errors after implementation.** Once the messages are implemented, their use should be studied to examine the effects of the various factors on pilot performance. This would require comparing the number of transmissions issued to the number of errors observed for each message in the context of other messages in the transmission. This would be analyzed by the factors associated with complexity as described above to help define the relative contribution of the various factors. This information could be used to develop or refine error mitigation strategies.
- **Continue to refine procedures for negotiation and execution of 4D clearances.** Both the International Civil Aviation Organization (ICAO) draft Concept of Operations for TBO (2019) and the FAA Vision for Trajectory Based Operations (2017) identify the introduction of TBO as an evolutionary process. The messages and procedures to be used by flightcrews, dispatch, and air traffic control need to be defined and designed to minimize the probability of error. Furthermore, the challenges and operational impacts on the flight deck associated with TBO will need to be periodically assessed as the specific interactions between TBO tasks and other flight deck tasks change over time.

- **Continue to work within ICAO and RTCA to progress global harmonization of procedures for clearance negotiation.** The goals for TBO of increased capacity, efficiency, and predictability with reduced fuel burn and emissions are universal. However, as the 2018 report on the State of Harmonization between the U.S. NextGen and European SESAR programs states, the modernization strategies for Data Comm by NextGen and SESAR do not completely align in terms of present and planned capabilities (SESAR Joint Undertaking /Federal Aviation Administration, 2018). This means that pilots will continue to deal with differing capabilities in different airspaces. Continued participation within ICAO and RTCA will help to ensure that the modernization efforts are as harmonized as possible and specific differences in phraseology used for clearance negotiation can be highlighted to U.S. users and monitored as appropriate to determine that no safety issues exist.

10. References

Battiste, V., Lachter, J., Ligda, S., Nguyen, J.H., Bacon, L.P., Koteskey, R.W., & Johnson, W.W. (2011). Is ACARS and FANS-1A just another data link to the controller? In G. Salvendy & M.J. Smith (Eds.) *Human Interface, Part II: HCII 2011, LNCS 6772*, 453-462.

Brandt, S.L., Lachter, J., Dao, A-Q.V., Battiste, V., & Johnson, W.W. (2011). Flight deck workload and acceptability of verbal and digital communication protocols. In G. Salvendy & M.J. Smith (Eds.) *Human Interface, Part II: HCII 2011, LNCS 6772*, 463-472.

Cardosi, K. (1993). *An analysis of en route controller-pilot voice communications.* DOT/FAA/ RD-93/11.

Cardosi, K. & Abbott, K. (2014). Human Factors Considerations for North Atlantic and Half Degree Waypoints. Unpublished memorandum.

Cardosi, K., Brett, B., & Han, S. (1996). *An analysis of TRACON (Terminal Radar Approach Control) controller-pilot voice communications*. DOT/FAA/AR-96-66.

Chandra, D., Kendra, A., Zuschlag, M., & Whittaker-Walker, I. (2020). *flight deck human factors issues in lateral deviations during North Atlantic (NAT) flight operations.* DOT-VNTSC-FAA-20-06.

Chandra, D., Lennertz, T., & Cardosi, K. (2019). Flight deck human factors issues in vertical and lateral deviations during North Atlantic Flight Operations. Presented at the *38th Digital Avionics System Conference* September 8-12, 2019, San Diego, CA.

Dunbar, M. McGann, A., Mackintosh, M., Lozito, S. (2001). *Re-examination of mixed media communication: the impact of voice, data link and mixed air traffic control environments on the flight deck*. NASA/TM—2001–210919.

Federal Aviation Administration, Flight Deck Automation Working Group (2013). *Operational use of flight path management systems*. Final report of the Performance-based operations Aviation Rulemaking Committee/Commercial Aviation Safety Team Flight Deck Automation Working Group.

Federal Aviation Administration (2019). *The future of the NAS*. Washington, DC.

Federal Aviation Administration (2018). *NextGen's path to Trajectory Based Operations (TBO)*, TRB Review.

Federal Aviation Administration (2018). *FAA Strategic Plan, FY19-FY22*. Washington, DC.

Federal Aviation Administration (2017). Vision for Trajectory Based Operations (Draft Version 2.0).

Green, S.M., Bilimoria, K.D., Ballin, M.G. (2000). Distributed air-ground traffic management for en route operations. *AIAA Guidance, Navigation, and Control Conference*. Denver, CO.

L3 Harris (2021). *Pilot handbook U.S. domestic Controller/Pilot Datalink Communication (CPDLC) operations*. https://www.l3harris.com/sites/default/files/2020-09/pilot-handbook-us-domestic-en-route-controller-pilot-datalink-communication.pdf.

International Civil Aviation Organization (ICAO) (2016). *Procedures of air navigation services: air traffic management,* Doc 4444, 16th Edition.

International Civil Aviation Organization (ICAO) (2017). *Global operational data link (GOLD) manual*, Doc 10037, First edition.

International Civil Aviation Organization (ICAO) (in press). *Global operational data link (GOLD) manual,* Doc 10037, 2nd Edition.

International Civil Aviation Organization (ICAO) (2022). *North Atlantic operations and airspace manual* (NAT Doc 007, V.2022-1).

International Civil Aviation Organization (ICAO) North Atlantic System Planning Group (NAT SPG) (2021). North Atlantic operations bulletin serial number: 2017 004_Rev 1 Subject: NAT data link special emphasis items.

International Civil Aviation Organization (ICAO) North Atlantic System Planning Group (NAT SPG) (2022). North Atlantic operations bulletin serial number: 2017 004_Rev 02 Subject: NAT data link special emphasis items.

International Civil Aviation Organization (ICAO) (2021). North Atlantic operations bulletin serial number: 2017 002_Rev 4 Subject: Oceanic Errors Safety Bulletin (OESB).

International Civil Aviation Organization (ICAO) (2020). North Atlantic System Planning Group (NAT SPG) 2019 Annual Safety Report. International Civil Aviation Organization (2019). TBO Concept V.11.0

International Civil Aviation Organization (ICAO) (2016). Annex 10 aeronautical telecommunications, Volume II communication procedures including those with PANS status, 7th Edition.

Johnson, W.W., Lachter, J., Battiste, V., Lim, V., Brandt, S., Koteskey, R.W., Dao, A-Q.V., Ligda, S.V., & Wu, S-C. (2011). An examination of selected Datacom options for the near-term implementation of trajectory based operations. *30th Digital Avionics Systems Conference*. Seattle, WA.

Kraft, T. (2014). *A study on the use of conditional clearances*. DOT/FAA/TC-14/58. Washington, DC. Federal Aviation Administration.

Lee, P. U., Darcy, J. F., Mafera, P., Smith, N., Battiste, V., Johnson, W., Mercer, J., Palmer, E., & Prevôt, T. (2004). trajectory negotiation via data link: Evaluation of human-in-the-loop simulation. *Proceedings of HCI-Aero 2004: International Conference on Human-Computer Interaction in Aeronautics.* Toulouse, France.

Lennertz, T., Cardosi, K. (2015). *Flightcrew procedures for controller pilot data link communications (CPDLC).* DOT/FAA/TC-15/56.

Lennertz, T., Cardosi, K., & Yost, A. (2019). *The effects of conditional clearances on altitude deviations.* DOT-VNTSC-FAA-19-04.

McGann, A., Lozito, S., & Corker, K. (1992). Cockpit data link displays: An evaluation of textual formats.

SAE Transactions, 101, 1969–1974. http://www.jstor.org/stable/44733153

Morrow, D. & Rodvold, M. (1993). *The influence of ATC message length and timing on pilot communication*. NASA Contractor Report 177621.

Mueller, E., & Lozito, S. (2008). flight deck procedural guidelines for datalink trajectory negotiation. *Proceedings of the 26th Congress of International Council of the Aeronautical Sciences*, 1-19.

Portugal. (2010). Use of AT and BY in CPDLC messages, WP/22, 03/04/2010, Presented at *35th Meeting of North Atlantic Air Traffic Management Group*, Paris, France.

Prevôt, T., Callantine, T., Kopardekar, P., Smith, N., Palmer, E., Battiste, V. (2004). Trajectory-Oriented Operations with limited delegation: An evolutionary path to NAS modernization. *AIAA 4th Aviation Technology, Integration, and Operations (ATIO) Forum*. Chicago, IL.

Prevôt, T., Lee, P., Callantine, T., Smith, N., & Palmer, E. (2003). Trajectory-Oriented time-based operations: Results and recommendations. *4th USA/Europe Air Traffic Management Research and Development Seminar*, *Air-Ground Cooperation Track*. Budapest, Hungary.

Prinzo, O.V., Hendrix, A.M., & Hendrix, R (2009). *The outcome of ATC message length and complexity on en route pilot readback performance*. DOT/FAA/AM-09/2.

Prinzo, O.V., Hendrix, A.M., & Hendrix, R (2006). *The Outcome of ATC Message Complexity on Pilot Readback Performance*. DOT/FAA/AM-06/25.

Rantanen, E. & Kokayeff N. (2002). Pilot error in copying air traffic control clearances. *Proceedings of the Human Factors and Ergonomics Society 46th Annual Meeting*, p. 145-149. Santa Monica, CA.

SESAR Joint Undertaking /Federal Aviation Administration (2018). NextGen – SESAR State of Harmonization.

Skaltsas, G., Rakas, J. &, Karlaftis, M. (2013). An analysis of air traffic controller-pilot miscommunication in the NextGen environment. *Journal of Air Transport Management*, *27*, 46-51.

Smith, N., Brown, J. A., Polson, P, & Moses, J. (2001). An assessment of flight crew experiences with fans-1 controller-pilot data link communication. Proceedings of *the 4th USA/Europe Air Traffic Management Research and Development Seminar, Air-Ground Cooperation Track*, Santa Fe, NM.

Smith, N.M., Lee, P.U., Prevôt, T., Mercer, J., Palmer, III, E.A., Battiste, A., Johnson, W. (2004). A human-in-the-loop evaluation of air-ground trajectory negotiation. *AIAA 4th Aviation Technology, Integration and Operations (ATIO) Forum.* 20-22 September 2004, Chicago, IL.

United Kingdom (2010). Ambiguous CPDLC Phraseology, WP/18, 03/03/2010, Presented at 35th Meeting of North Atlantic Air Traffic Management Group, Paris

Weber, R., & Crűck, E. (2007). Subliminal ATC utilizing 4D trajectory negotiation. *2007 Integrated Communications, Navigation and Surveillance Conference*, 2007, pp. 1-9, doi: 10.1109/ICNSURV.2007.384156.

U.S. Department of Transportation
John A. Volpe National Transportation Systems Center
55 Broadway
Cambridge, MA 02142-1093

617-494-2000
www.volpe.dot.gov