The Effects of Conditional Clearances on Altitude Deviations

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

June 26, 2019

DOT-VNTSC-FAA-19-04

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

Notice

REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 26, 2019	3. REPORT TYPE AND DATES COVERED Final report

4. TITLE AND SUBTITLE The Effects of Conditional Clearances on Altitude Deviations	5a. FUNDING NUMBERS 51FB70
6. AUTHOR(S) Tracy Lennertz, Kim Cardosi, & Alan Yost	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-19-04
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)

The complexity of communication between pilots and air traffic controllers will increase with the implementation of new traffic management capabilities that depend on Controller Pilot Data Link Communication (CPDLC). Here, we examine the relationship between conditional clearances (defined as messages that include a condition on when an action is to be started or completed) and altitude deviations. The purpose of this analysis is to identify causal and contributing factors to the pilot errors observed and recommend error mitigation strategies. To understand the relationship between conditional clearances and altitude deviations, we analyzed 1) reports submitted to the Aviation Safety Reporting System (ASRS), 2) CPDLC communications in United States (US) oceanic airspace from 2014-2017, and 3) recent Large Height Deviations in North Atlantic airspace and altitude deviations reported in the New York Oceanic Control Area. The results further our understanding of human factors issues that contribute to pilot error with complex clearances, and can be used to facilitate the development of procedures and training to ensure effective and efficient human system integration in NextGen capabilities.

14. SUBJECT TERMS Controller Pilot Data Link Communication, CPDLC, Data Comm, data link, datalink, conditional clearances, Large Height Deviations, ATC clearance, NextGen, complex clearances	15. NUMBER OF PAGES 44
	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		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	Liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		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/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	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		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
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/m^2	candela/m^2	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/in^2

*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)

Contents

Table of Figures

Table of Tables

Acronyms

ARTCC	Air Route Traffic Control Centers
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATM	Air Traffic Management System
CPDLC	Controller Pilot Data Link Communications
Data Comm	Data Communications
DM	Downlink Message
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FAR	Federal Aviation Regulations
FL or F	Flight Level
FMC	Flight Management Computer
GOLD	Global Operational Data Link Manual
HLA	High Level Airspace
ICAO	International Civil Aviation Organization
IFALPA	International Federation of Air Line Pilots' Association
LHD	Large Height Deviation
NAT	North Atlantic
NAT ATMG	North Atlantic Air Traffic Management Group
NAT CMA	North Atlantic Central Monitoring Agency
NextGen	Next Generation Air Transportation System
OCA	Oceanic Control Area
PANS-ATM	Procedures for Air Navigation Services – Air Traffic Management
PD	Pilot Deviation
RA	Resolution Advisory
SOP	Standard Operating Procedure
TCAS	Traffic Collision Advisory Systems
TBO	Trajectory Based Operations
UM	Uplink Message
US	United States
WATRS	West Atlantic Route System
WG	Working Group
WILCO	Will Comply
ZAK	Oakland Oceanic Control Area
ZAN	Anchorage Oceanic Control Area
ZNY	New York Oceanic Control Area

Preface

This report was prepared by the Transportation Human Factors Division of the Safety Management and Human Factors Technical Center at the US Department of Transportation, John A. Volpe National Transportation Systems Center. It is intended to satisfy the deliverable "Draft Report on Oceanic Large Height Deviations Causal Factors" in the FB70C1 Interagency Agreement (IAA) titled NextGen Human Factors: Mitigations to Address Emerging and Strategic Risks associated with Complex Clearances. Work on this report was funded via the Federal Aviation Administration (FAA) RE&D System Development—NextGen Air/Ground Integration PLA.

We thank ANG-C1, AVS, and AFS for sponsoring this research and for the technical guidance provided by the FAA.

For questions or comments, please e-mail Tracy Lennertz, tracy.lennertz@dot.gov.

Executive Summary

The complexity of communication between pilots and air traffic controllers is expected to increase with the implementation of new traffic management capabilities, such as Trajectory Based Operations. In anticipation of this and other Next Generation Air Transportation System (NextGen) applications that are dependent on Controller Pilot Data Link Communication (CPDLC), we examine the relationship between conditional clearances and altitude deviations. The purpose of this analysis is to identify causal and contributing factors to the pilot errors observed and recommend error mitigation strategies.

Conditional clearances are messages that include a condition, either a time or a place, on when an action—such as a climb or descent—is to be started or completed. 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. Past work (Kraft, 2014) found that "CLIMB TO REACH [level] BY [time]" was the most common conditional clearance in New York Oceanic Control Area (OCA) from 2007 to 2012. However, 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. This combination of clearances in the same transmission requires the flightcrew to comply with two restrictions: the first restriction is the place or time for starting the climb, and the second is the point by which the aircraft must reach the level. While the frequency of use of this combination of clearances varied across facilities, the type of pilot error was consistent—flightcrews climbed too early, especially when the message was issued via CPDLC rather than voice.

To further understand the relationship between conditional clearances and altitude deviations, we analyzed 1) reports submitted to the Aviation Safety Reporting System (ASRS), 2) CPDLC communications in United States (US) oceanic airspace from 2014-2017, and 3) recent Large Height Deviations (LHDs) in North Atlantic airspace and altitude deviations reported in the New York OCA. The ASRS analysis observed 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. Our analysis of US oceanic CPDLC communications re-confirmed that "BY [time]" messages are relatively frequent compared to "AT [time]" messages, and that the combination of these messages is still used in oceanic airspace. Finally, our analysis of altitude deviations generally replicated the findings of Kraft (2014). While the number of reported deviations has declined over time, the proportion of deviations involving conditional clearances remains comparable. This analysis confirmed that a combination of clearances known to be a source of pilot error still results in altitude deviations with pilots acting on the more frequent second clearance without 'seeing' the first, less frequent clearance.

The results of this study suggest a need to 1) further minimize the use of conditional clearances when operationally feasible, 2) promote standard operating procedures for CPDLC message review in flightcrew training, and 3) develop guidance for pilots and controllers on clearance negotiation. The results further our understanding of human factors issues that contribute to pilot error with complex clearances, and can be used to facilitate the development of procedures and training to ensure effective and efficient human system integration in NextGen capabilities.

Introduction

As part of the increased flexibility in routing afforded by Next Generation Air Transportation System (NextGen) applications, such as with Trajectory Based Operations (TBO), the complexity of both routes to be flown and flightcrew and air traffic controller (ATC) communications will increase with increasingly complex routes (FAA, 2016). In the near term, as traffic increases over the ocean, so will the frequency of negotiation—with pilots questioning about the availability of flight levels and controllers querying the pilot about the ability to accept a specific level. When the flight level that the pilot has requested is not currently available, but will be available at a future time, the controller may issue a conditional clearance that allows the pilot to change flight level at a future time. This adds a layer of complexity to the pilots' task and can result in an altitude deviation if the pilot initiates the maneuver early.

The purpose of the current work is explore the relation between conditional clearances and altitude deviations, to identify human factors issues associated with these conditional clearances, and to recommend mitigations for the identified issues. An understanding of these issues will facilitate the development of standard operating procedures and training requirements that ensure effective and efficient human system integration in NextGen capabilities. To that end, we analyzed: 1) reports submitted to the Aviation Safety Reporting System (ASRS), 2) recent CPDLC communications in United States (US) oceanic airspace, and 3) recent Large Height Deviations (LHDs) in North Atlantic airspace and altitude deviations reported in the New York Oceanic Control Area (OCA), including causal and coincident factors and their relation to complex clearances.

Our focus was on complex clearances that include a condition that refer to a future action (e.g., "AT [time]") and require the flightcrew to remember to complete the action later. Today's aircraft do not have a means to automate the loading of a conditional altitude clearance into the Flight Management Computer (FMC) and then execute the clearance when the condition is met. The flight deck may be equipped with an automated reminder for the flightcrew when an action should be initiated (e.g., on a Boeing 787), but no similar assistance exists to prevent the flightcrew from acting on the clearance prematurely.

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. The conditional clearances "AT [time/position] CLIMB/DESCEND TO [level]" and "CLIMB/DESCEND TO REACH [level] BY [time/position]" were first identified as problematic in 2010. Both Portugal (NAT ATMG/35 WP 22) and the United Kingdom (NAT ATMG/35 WP 18) presented papers to the International Civil Aviation Organization (ICAO) North Atlantic (NAT) Air Traffic Management Group (ATMG) identifying the risk of altitude deviations induced by these conditional clearances. This risk was explored in more detail by Kraft (2014) who quantified the relation between conditional clearances (as shown in Table 1) and 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. A LHD that results in a loss of lateral or longitudinal separation from another aircraft is classified as "risk bearing". Risk-bearing LHDs provide the basis for estimating vertical risk and are compared to a specific safety criterion (i.e., a target level of safety).

Table 1. Conditional clearances (from Kraft, 2014).

	Uplink Message (UM) Number	**Message** (per ICAO Doc 4444, 2007; FANS 1/A implementation is shown in italics)
"AT"	UM 21	AT [time] CLIMB TO [level] *AT [time] CLIMB TO AND MAINTAIN [altitude]*
	UM 22	AT [position] CLIMB TO [level] *AT [position] CLIMB TO AND MAINTAIN [altitude]*
	UM 24	AT [time] DESCEND TO [level] *AT [time] DESCEND TO AND MAINTAIN [altitude]*
	UM 25	AT [position] DESCEND TO [level] *AT [position] DESCEND TO AND MAINTAIN [altitude]*
"BY"	UM 26	CLIMB TO REACH [level] BY [time]
	UM 27	CLIMB TO REACH [level] BY [position]
	UM 28	DESCEND TO REACH [level] BY [time]
	UM 29	DESCEND TO REACH [level] BY [position]

Kraft observed that in the US NAT oceanic airspace, "CLIMB TO REACH [level] BY [time]" (UM 26) was the most commonly used conditional clearance, issued at least ten times more often than any of the other conditional clearance message elements. He also examined the relation between conditional clearances and their contribution to risk-bearing LHDs in the NAT Region from 2007 to 2012. He found even though "CLIMB TO REACH [level] BY [time]" (UM 26) was the most commonly used conditional clearance, the use of the "AT [time] CLIMB TO [level]" (UM 21) clearance combined with the "CLIMB TO REACH [level] BY [time]" (UM 26) was significantly more likely to contribute to a LHD than the use of the "CLIMB TO REACH [level] BY [time]" (UM 26) clearance alone. In addition, Kraft examined the frequency of conditional clearances in oceanic airspace, as well as LHDs that were associated with their use. The highest proportion of LHDs by conditional clearance message type was seen with the combination of "AT [time] CLIMB TO REACH [level]" and "CLIMB TO REACH [level] BY [time]" in the same transmission. This combination of clearances in the same transmission instructs the flightcrew to adhere to two restrictions regarding the level in the clearance. The first restriction is the place or time for starting the climb. The second restriction is the point at which the aircraft must reach the level in the clearance. While the frequency of use of this combination of clearances was found to vary widely across facilities, the effect on LHDs was consistent—flightcrews climbed too early. This was particularly the case when the message was issued via CPDLC compared to voice. From a human factors standpoint, this is not surprising, since messages transmitted via CPDLC cannot convey the same inflection of emphasis as voice. The best use of CPDLC for complex messages and clearance negotiation needs to be understood to support the implementation of advanced NextGen concepts.

Analysis of Reports Submitted to the Aviation Safety Reporting System

To further understand the relationship between conditional clearances and LHDs, we examined relevant reports submitted to the Aviation Safety Reporting System (ASRS). Note that ASRS reports cannot be used to infer the frequency of events, given that not all events are submitted to the reporting system, and, of those submitted, not all entered into the database. ASRS reports can, however, provide insight into the causal factors surrounding the relationship between conditional clearances and LHDs.

We searched the ASRS database for reports submitted between January 2012 and January 2018 by air carrier captains or first officers who reported an event that was classified as an excursion from assigned altitude while the aircraft was in the 'cruise' phase of flight (as opposed to take-off or landing). These conditions were chosen to capture the situations resulting in the highest proportion of LHDs associated with the conditional clearances identified in Table 1. This search yielded 210 reports, however, conditional clearances were not cited in any of them. In fact, only a relatively small percentage (5%) were due to miscommunications of any sort, this includes accepting clearances intended for other aircraft (usually associated with similar call signs), and communication problems with foreign air traffic controllers. Also interesting was the relatively few reports (3%) attributing the altitude deviation to pilot errors in programming the FMC, although an additional 2% were attributed to the complexity of the arrival procedure or execution of a "Descend Via" clearance.

By far, the overwhelming causal factor identified in half of these cases of altitude excursions was turbulence and other weather factors. The second most common factor identified in 21% of the reports from this search was a combination of various mechanical malfunctions (and the resulting distractions), and a variety of 'problems' with the autopilot (which could also be due to pilot error with autopilot functions). The third most common causal factor identified in these altitude excursions was a response to a Traffic Collision Advisory System (TCAS) Resolution Advisory (RA) or otherwise changing altitude to avoid collision with another aircraft, and responding to TCAS RAs that were later discovered to be 'false'.

While the original intention was to analyze ASRS reports of altitude deviations reported by air carrier pilots to determine the percentage of these reports attributable to conditional clearances, this analysis determined that such an approach would not be fruitful. Nor was it feasible to search for reports involving conditional clearances, since there are no codified search criteria for different types of clearances. Searches on specific terms, however, can be conducted.

A subsequent search of all reports containing the text "conditional clearance" yielded 25 reports submitted between February 1999 and July 2007. Of the reports in this search, almost half (48%) describe conditional clearances during airport ground operations. Others described events involving clearances that might include a condition, but did not include the specific type of clearances or involve the specific pilot errors included in the present study. For example, one of the reports describes an instance in which the crew forgot to descend after receiving the following clearance, "CROSS 70 DME AT 27,000, DESCEND AT PILOT'S DISCRETION". An additional two reports from flightcrews requested a general prohibition of conditional clearances (ACN 233751 & ACN 411233).

Only two of the reports resulting from the search for "conditional clearance" were germane to the current focus. In both cases, the crew later realized that they missed the condition "AT [time]" which resulted in climbing early. The following are excerpts from those two reports which were submitted in 1997 and 1999, respectively. Abbreviated words have been spelled out.

> *We received a FANS [Future Air Navigation System] message to climb to FL330 (we were at FL310). The captain printed the message, verified the plane number and flight number but somehow missed the phrase 'AT TIME'. We climbed and reported level at FL330 [12 minutes early]. ATC advised us to return to FL310 which we immediately did. This problem could be avoided if conditional clearances were not given. Just give us a clearance when we are able to comply (ACN 382400).*

> *Requested climb to FL350 due to aircraft performance. Xx39z -- at xy08z climb to and maintain FL350. Xx40z -- response wilco. Both pilot flying and pilot not flying read and verified the xx39z uplink. Both misread the clearance. The 'AT [time] CLIMB TO' AT [time], did not register in our brains -- we only saw the 'CLIMB TO AND MAINTAIN FL350'* (ACN 426098).

Since the search for reports containing the text "conditional clearance" only yielded 25 reports, an even broader search for reports containing the word "conditional" was conducted. While this search yielded an additional 117 reports, only two were relevant. In both reports, the pilots cite fatigue as a contributing factor to their failure to notice the "AT [time]" restriction:

> *At approximately xx35z the captain (pilot not flying) requested a climb from FL310 to FL350. At xx39z we were cleared to 'AT xx08 CLIMB TO AND MAINTAIN FL350.' at this time we were using CPDLC (FANS) for comm, so we printed this clearance and both read the clearance. For some reason, which we both contribute to fatigue, we missed the contingency 'AT xx08...' and climbed right away. At xx54 I sent a message 'level FL350' and about that time changed seats with the relief pilot. At xy04z the pilot in the seat sent a position report which included the Flight level after which they received a message from NADI controller that read 'you were not cleared at fl350 until xx08.' Basically we had climbed approximately 26-28 mins early. Both the captain and I (pilot flying) were very tired when this incident occurred. We had been flying for about 5 1/2 hrs and it was about zz30 in our home towns. It was right before we were to take our break. We both are certain that we would not have missed this contingency if we were not tired. I really feel that contingency clearances should not be given over FANS and especially this time of night when crews are tired. I don't excuse our error and didn't think this would ever occur to me. Supplemental info from ACN 426344: action is being taken against us by the FAA and my personal feelings are that I am extremely upset with FANS conditional clearances. I am going to reject any I receive. The problem lies with phraseology. They*

should state, 'maintain fl330 then state at xy08 climb and maintain fl350.' That would have solved the prob. (ACN 426352, 1999). (Note, this may be a report of the same incident described above in ACN 426098 submitted by the other crewmember).

Cruising westbound at FL340 …over the north Atlantic we had been requesting clearance for a higher cruising alt for some time. … at xb50z a CPDLC message came in from ZZZ oceanic to CLIMB AND REPORT REACHING FL370. We accepted this clearance, climbed to FL370, and at xb53z an auto report was sent via CPDLC confirming that we were level at FL370. At xc07z CPDLC message came in and it said, 'confirm climb clearance received said AT TIME xc00 climb.' Looking back at the original clearance message, we realized that it said, 'MAINTAIN FL340, AT xc00z CLIMB TO AND MAINTAIN FL370, REPORT LEVEL FL370.' We saw the climb clearance that we were anticipating, but missed the time to begin the climb. At this same time, xc07z, we were conducting a crew change when a message came in to call ATC, which I did upon reaching the gate. Observations: 1) we saw the clearance that we were expecting and missed the conditional statement. 2) It might be safer to only issue a clearance when it can be executed i.e., not at a conditional time. 3) Fatigue may have contributed to our missing the conditional statement. I was unable to sleep on my previous rest break (ACN 795258, 2008).

To search for more of the types of conditional clearances included in the Kraft (2014) analysis, a search for reports containing the words “CLIMB TO REACH” and “DESCEND TO REACH” was conducted. This yielded 11 reports, only four of which were submitted by pilots, but none of which were relevant to this investigation. Of the seven reports submitted by air traffic controllers, the most common theme was controllers lamenting the fact that the pilot’s response to the clearance was not adequate to maintain the required separation. As one controller noted in a 2017 report, “I would like that the pilot be instructed that if he cannot meet a climb restriction to advise as soon as possible so an alternative action can be taken immediately” (ACN 1416806).

One of the 11 reports was unique in that it described the exact situation highlighted as problematic in Kraft (2014) but attributed it to a unique source of error. In this report, the air carrier aircraft requested FL390. The controller responded with 'Unable Higher Due Traffic'. The aircraft responded 'Roger'. Fourteen minutes later, the controller sent the clearance: ‘Maintain FL380; *At Time* XB:00Z (ten minutes from when the clearance was composed) *Climb and Maintain FL390; Climb to Reach FL390 by XB:05Z; Report Level FL390* (emphasis added)’. The pilots (operating an air carrier wide-body aircraft under Federal Aviation Regulations (FAR) Part 121) accepted the clearance and began to climb prematurely. When the aircraft reported level at FL390 earlier than the controller expected, the controller sent a free text message asking to confirm that they were at FL390 reporting that:

I gave them a clearance to maintain FL380 until XB00z due traffic. The flight informed me that the plane automatically transferred FL390 to their mode control altitude window. Since they were expecting FL390. The pilot then executed the change and said *that it looks like a software issue because the system did not recognize the first part of the clearance to maintain until [time] but instead transferred FL390. I am not sure if this explanation from the pilot was an attempt to cover a mistake or if it really happened but this situation could have been much worse if the two aircraft were 2 or 3 minutes closer together than they were. I, because of experience, added in a buffer to the time of several minutes as is my practice anyway, but if I had not done that this situation might not have been good at all. We should check the software in aircraft X to see if it is compatible with ATOP complex clearances and insure that this does not happen again* (ACN 1297363, 2015).

In all of the previous incidents reviewed here, the flightcrew acknowledged that they missed the "AT TIME" portion of the clearance. The most interesting aspect of this 2015 report is that no air carrier aircraft currently has the capability to load the "AT [time]" clearances to execute the clearance at a later time. If the report is straightforward (and not an attempt to excuse the error), then neither the pilot nor the controller were aware of this fact.

In summary, the most likely cause of the LHDs resulting from the "AT TIME" and "CLIMB TO REACH BY" set of clearances is that the pilots overlook the first clearance (which they see occasionally) and only "see" the second (which they see much more often). Since the nature of the pilot error in these cases is largely understood, and since only one report of the hundreds analyzed revealed any new insights into the possible causes of LHDs associated with these conditional clearances, we next examined the current use of these clearances and their relation to LHDs to determine if the findings presented by Kraft (2014) were still affecting performance in the same way.

Analysis of Communication in US Oceanic Airspace

We examined oceanic data link communications from 2014-2017—that originated with a message from the controller to the pilot—in three Air Route Traffic Control Centers (ARTCCS): New York (ZNY), Oakland (ZAK), and Anchorage (ZAN). This data set included nearly 4 million CPDLC messages.

Figure 1 shows the total number of messages exchanged, by year, for each of the oceanic centers. Note, that the greatest number of messages is exchanged between pilots and controllers in Oakland (ZAK) oceanic airspace. Also of interest, is the increase in number of CPDLC messages exchanged by year, for each center—again, reflecting the overall traffic and equipage levels.

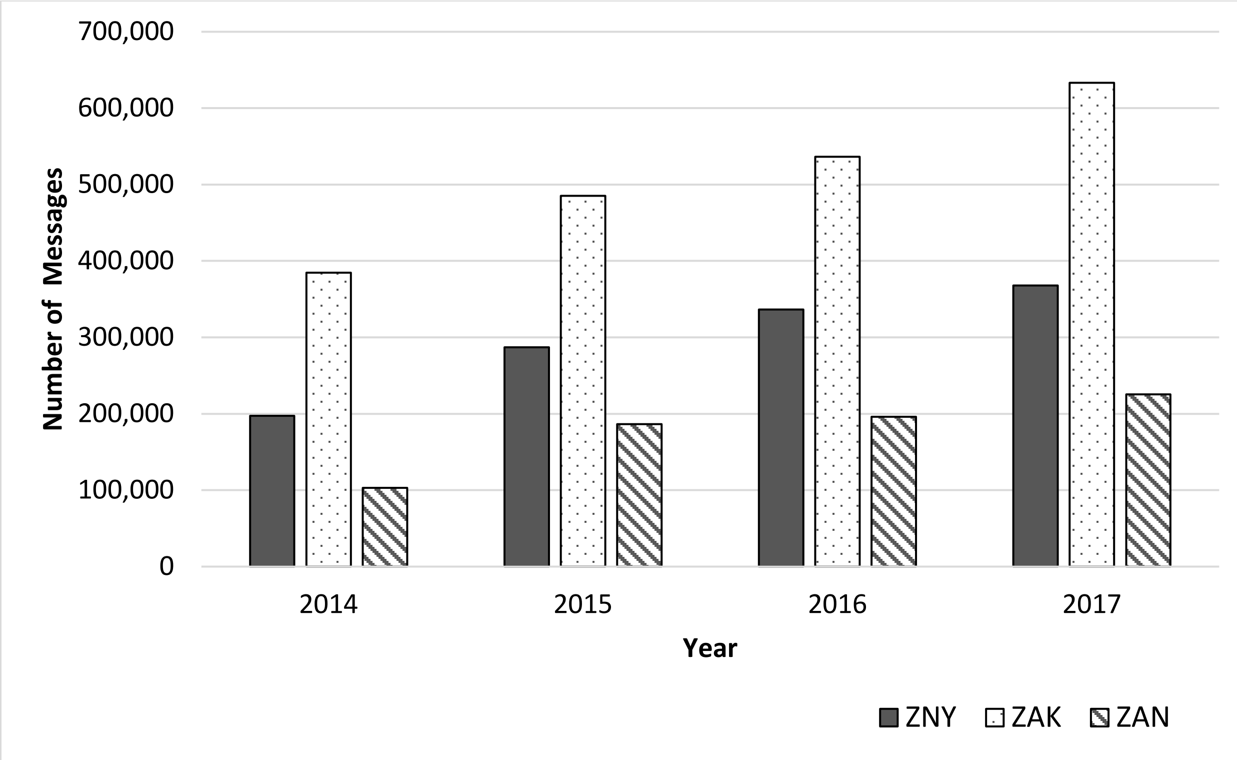

Figure 1. Total number of CPDLC messages exchanged—initiated by ATC—per year, by oceanic center.

Typical CPDLC message transmissions of conditional clearances—sent from ATC to the flightcrew—are shown in Table 2. In what follows, we examine the frequency of these communications in US oceanic airspace.

Table 2. Example CPDLC transmissions of conditional clearances.

	Message Number	Message
Example 1	UM 19	MAINTAIN [level]
	UM 21	AT TIME [time] CLIMB TO [level]
	UM 129	REPORT LEVEL [level]
Example 2	UM 26	CLIMB TO REACH [level] BY [time]
	UM 129	REPORT LEVEL [level]
Example 3	UM 19	MAINTAIN [level]
	UM 21	AT TIME [time] CLIMB TO [level]
	UM 26	CLIMB TO REACH [level] BY [time]
	UM 129	REPORT LEVEL [level]

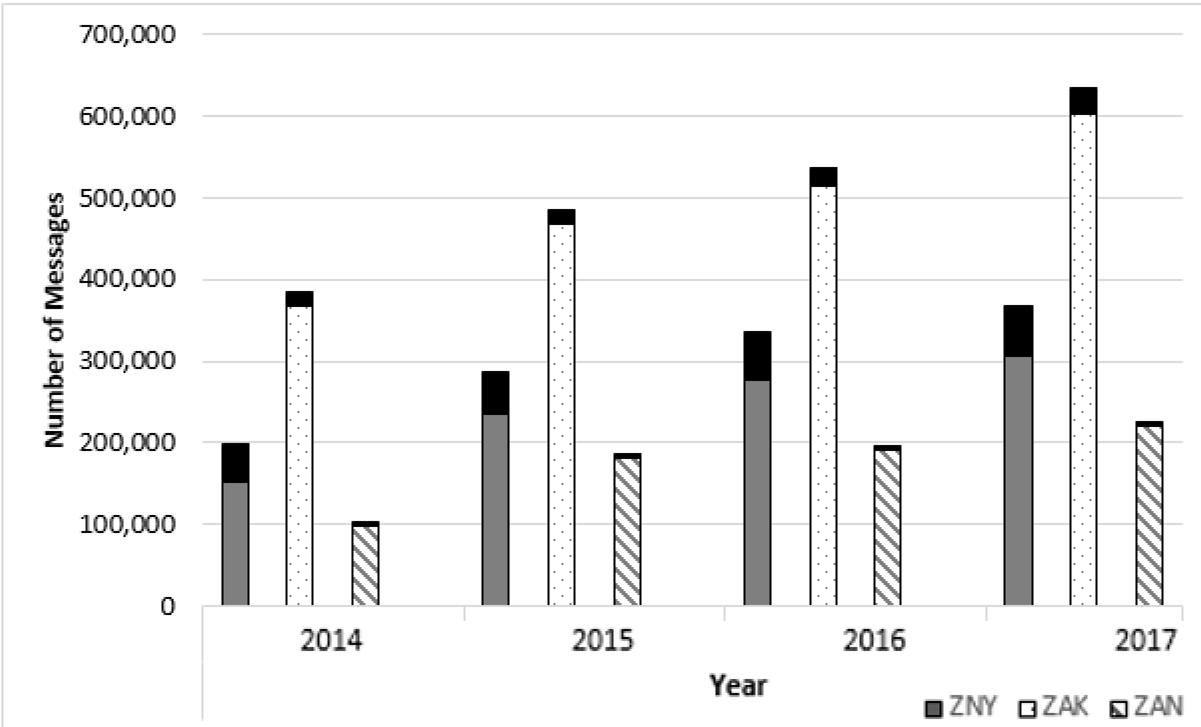

Figure 2. Total number of CPDLC messages exchanged—with conditional clearances shown in black, initiated by ATC—per year, by oceanic center.

As can be seen in Figure 2 the use of conditional clearances by center is not proportionate to the total number of clearances. While ZAK issues the most clearances overall, ZNY issues more conditional clearances. Given the differences in the number of conditional clearances issued by center, further analysis looked more closely at the frequency of use of each of the conditional clearances by center.

Frequency of Use by Message

Table 3 shows the frequency of use for each message by center in 2017. Note that instructions to climb (UM 21, 22, 26, and 27) would be expected to be more frequent in oceanic airspace than instructions to descend, as aircraft seek to climb to more efficient altitudes as they burn fuel and become lighter. Across centers the use of "CLIMB TO REACH [level] BY [time]" (UM 26) was by far the most commonly used conditional clearance of the set examined. It was also much more frequently used in ZNY than in ZAK (which issued more CPDLC clearances, overall). The instruction to “AT [time] CLIMB TO [level]” (UM 21) was much less common than UM 26, slightly less common than the use of “CLIMB TO REACH [level] BY [position]” (UM 27) but more commonly used than “AT [position] CLIMB TO [level]” (UM 22) The frequencies of use for each message by center by year (2014-2017) are provided in Appendix A, but show no discernable pattern.

Table 3. The frequency of use of each message, by center, in 2017.

Message Number	ZNY	ZAK	ZAN
UM 21	1,319	495	104
UM 22	190	105	103
UM 24	155	13	3
UM 25	36	4	4
UM 26	50,695	27,574	4,313
UM 27	2,243	59	542
UM 28	3,999	2,423	241
UM 29	1,677	21	38
Total	**60,314**	**30,694**	**5,348**

Message Combinations

As we have seen, the instruction to "AT [time] CLIMB TO [level]" (UM 21) which has historically been considered to be problematic and associated with the most altitude deviations was much less common than "CLIMB TO REACH [level] BY [time]" (UM 26), slightly less common than the use of "CLIMB TO REACH [level] BY [position]" (UM 27), but more commonly used than "AT [position] CLIMB TO [level]" (UM 22). Kraft (2014) first reported that it was actually the combination of UM 21 and UM 26 that was more problematic than the use of UM 21 alone. The combination of UM 21 and UM 26 in the same message was associated with more LHDs attributed to pilot error than UM 21 or UM 26 issued alone. (See Appendix B for examples of how this combination of messages is displayed to the pilot).

The first proposal to mitigate the errors observed with UM 21 was proffered in a working paper presented at the North Atlantic Air Traffic Management Group (NAT ATMG) by Portugal (NAT ATMG/35 WP 22). They proposed that any conditional clearance to change altitude in the future (i.e., "AT [time]" or "AT [position]") be preceded with UM 19 "MAINTAIN [altitude]" as the first message element. This guidance was promulgated by Kraft (2014) and was published in the *Global Operational Data Link (GOLD) Manual* (ICAO Doc 10037). The "MAINTAIN" message can provide an additional cue to crews that the new altitude clearance is not to be acted on upon receipt. This, however, is not required in US airspace (per NAT Doc 007, Attachment 7, 2018).

We examined the frequency with which this combination of clearances was issued by center between 2014 and 2017 (inclusive) and then examined the altitude deviations. Figure 3 shows the number of messages that include UM 21 ("AT [time] CLIMB"), with and without being preceded by UM 19 ("MAINTAIN [current altitude]").

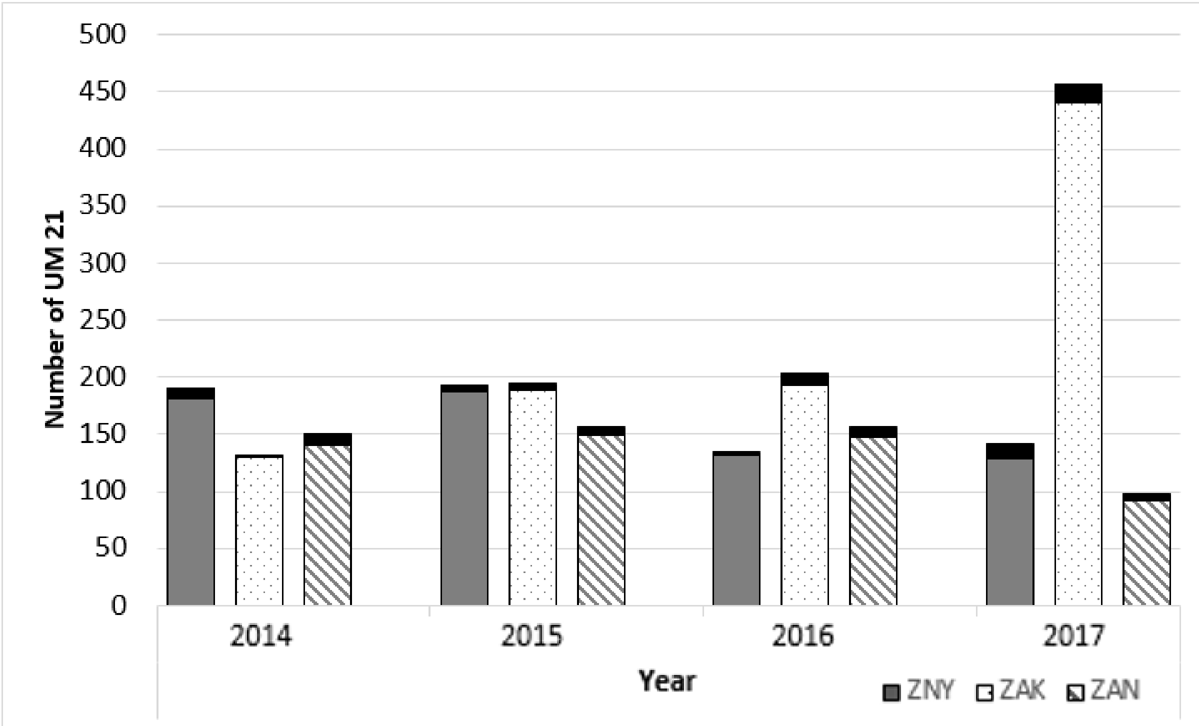

Figure 3. Frequency of UM 21 (“AT [time] CLIMB TO [level]”). The solid black portion of each bar represents the frequency that UM 21 (“AT”) was sent without UM 19 “(MAINTAIN [level])”.

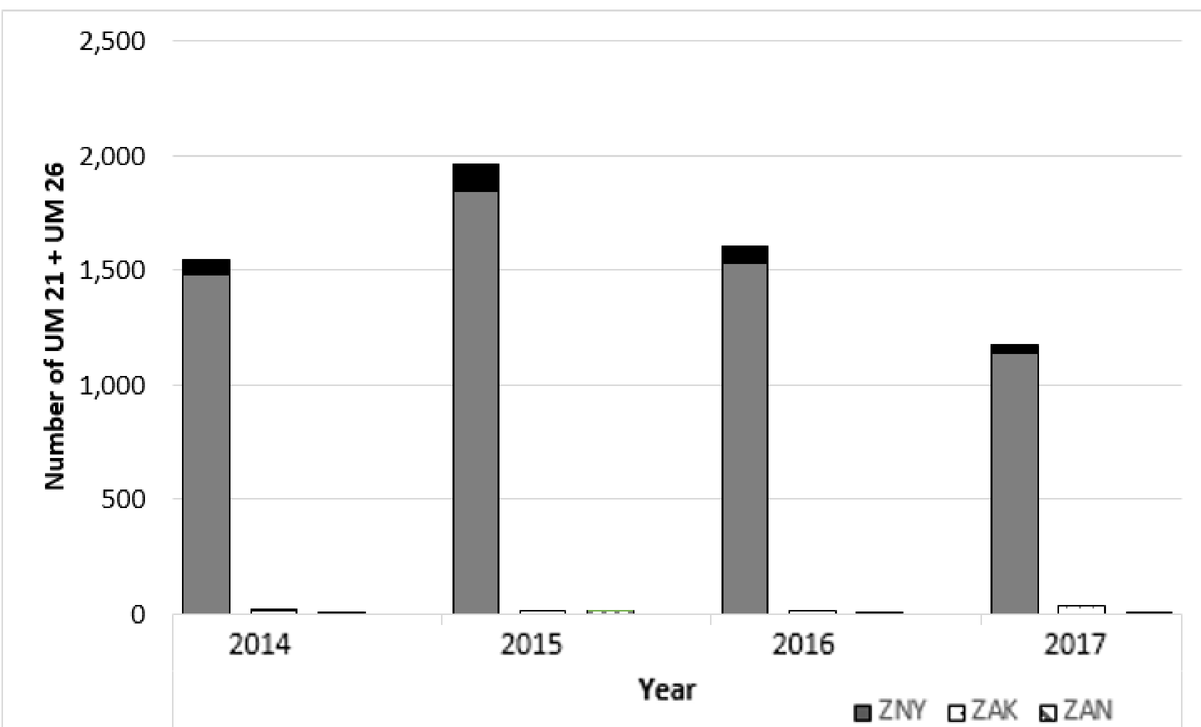

Figure 4. Frequency of UM 21 and UM 26, by year. The solid black portion of each bar represents the frequency sent without UM 19 (the instruction to maintain current altitude).

Figure 4 shows that the combination of UM 21 and UM 26 are most often sent by ZNY and used very rarely in ZAK and ZAN. In fact, in ZNY, most of the time that UM 21 is sent, it is accompanied by UM 26. For ZNY, in the majority of cases, UM 21 - UM 26 is preceded by UM 19, but not always. About 4% of UM 21 - UM 26 combinations *do not include* UM 19. A summary of this data is presented in Table 4.

Table 4. Frequency of UM 21 and UM 26, with and without UM 19, 2014-2017.

Center	With UM 19	Without UM 19
ZNY	6,001	288
ZAK	76	1
ZAN	36	2

Analysis of Altitude Deviations in the North Atlantic

This section examines the role of conditional clearances in altitude deviations in the North Atlantic. To mirror Kraft (2014), our analyses started with the safety occurrence data on LHDs in the North Atlantic from the ICAO North Atlantic Central Monitoring Agency (NAT CMA). To supplement these data, we also examined pilot deviations in the North Atlantic in the New York's airspace. Note, there is likely some overlap between these two data sets, as a subset of pilot deviations from ZNY are reviewed and discussed by the ICAO NAT Scrutiny Group. The degree of overlap, however, could not be assessed since identifying details are deleted.

LHDs in North Atlantic Airspace

There were 107 LHDs reported the NAT in 2017, by the ICAO NAT CMA. As shown in Figure 5, 23 of these LHDs were related to Air Traffic Controller (ATC) error (usually an error in controller-to-controller coordination), 15 were related to weather/turbulence, 10 were for an unknown reason, 9 were related to an emergency, 3 were related to difficulty with communication over the ocean, and one was related to a fuel urgency. Forty-six were identified by the Scrutiny Group as 'pilot error' or pilot climbing or descending 'without a clearance'.

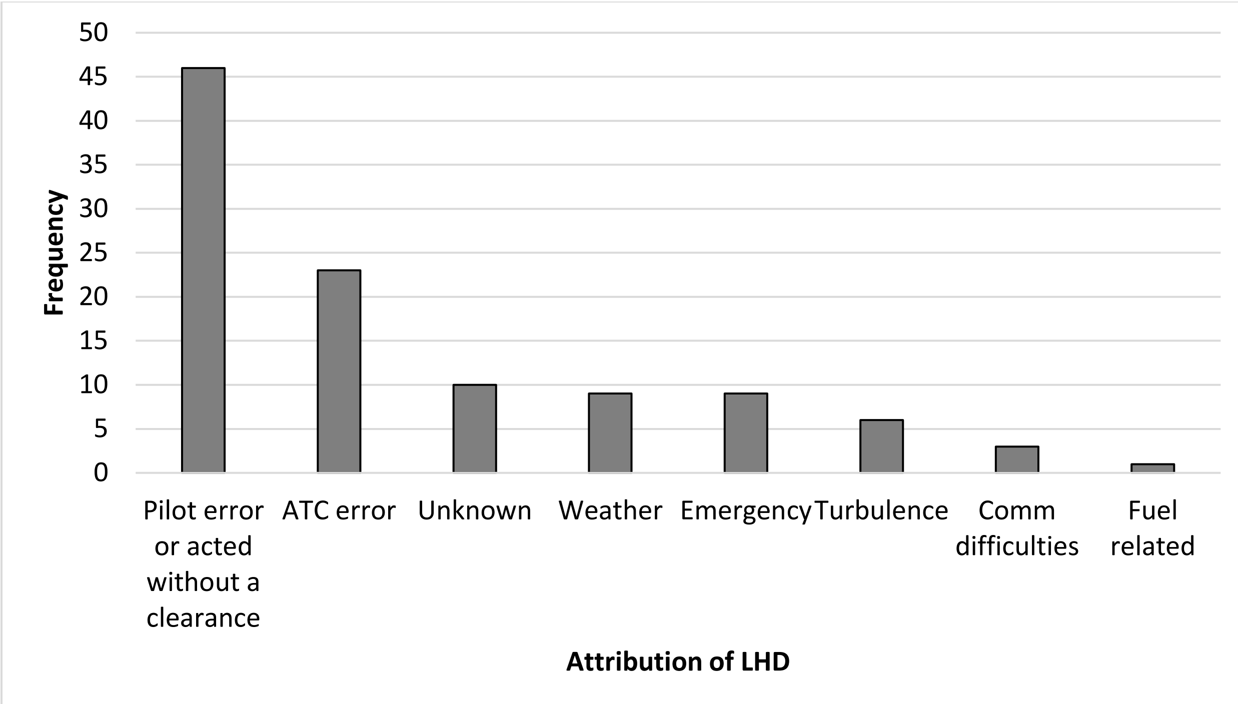

Figure 5. Distribution of causal factors of LHDs from the NAT CMA in 2017.

LHDs Attributed to Pilot Error

In 2017 there were 46 LHDs in the NAT attributed to pilot error. The descriptions of these events (as submitted to the Central Monitoring Agency) were analyzed to identify causal factors and error mitigation strategies. The distribution of LHDs by communication medium—CPDLC or voice (i.e., high frequency [HF] or very high frequency [VHF]) is shown in Table 5. The majority of errors were associated with clearances communicated via CPDLC, although the proportion of clearances conveyed to the pilot by voice is unknown.

Table 5. Frequency of NAT 2017 pilot LHDs by communication medium.

Communication Medium	Frequency
CPDLC	26
Voice	10
Unknown	10
Total	**46**

Each pilot LHD was further analyzed with regard to the resulting aircraft action —for example, whether the aircraft climbed or descended early, late, or without clearance—and any related factors—for example, whether a pilot request or conditional clearance was involved. Nine of the LHDs involved the communication of a conditional clearance (about 20%). The full distribution of pilot LHDs, with outcomes and related causal factors, is shown in Table 6.

Table 6. Frequency of pilot LHDs by outcome and related factors.

Outcome and Related Factors	Frequency
Climbed early	**6**
AFTER PASSING [position] CLIMB TO [level]	1
AT [position] CLIMB TO [level]	2
AT [time] CLIMB to [level]	1
AT [time] CLIMB to [level]; CLIMB TO REACH [level] BY [time]	1
Missed crossing restriction	1
Climbed late	**5**
AT [position] CLIMB TO [level]	1
CLIMB TO REACH [level] BY [position]	1
CLIMB TO REACH [level] BY [time]	2
Missed level restriction	1
Climbed without clearance	**20**
Accidently rejected clearance, then climbed	1
Climbed after WHEN CAN YOU ACCEPT	2
Difficulty with Comms	1
Followed flight plan instead of clearance	1
Overshot altitude	2
Requested	4
Requested, related to weather	2
Thought they had a level change	1
Took instruction for another aircraft	1
Unknown	5
Descended early	**2**
Missed crossing restriction	1
Time constraint	1
Descended late	**3**
Difficulty with Comms	1
Missed crossing restriction	1
Unknown	1
Descended without clearance	**7**
Aircraft performance	1
Confusion with re-clearances	1
Related to weather	3
Undershot altitude	1
Unknown	1
Other	**3**
Position report	3
Grand Total	**46**

Climb Clearances

Of the nine LHDs in this data set associated with a climb clearance, seven were identified as CPDLC and one was identified as transmitted via voice. The communication medium was not identified in the other LHD.

Climbed early

In six of the LHDs attributed to pilot error, the flightcrew climbed early. Five of these deviations involved a conditional clearance, and four of these clearances were issued by CPDLC. In one instance, the flightcrew received UM 21 and UM 26, "AT [time] CLIMB to [level] & CLIMB TO REACH [level] BY [time]" (note, UM 19, "MAINTAIN [level]" was also included.) Two deviations in this category involved a message with an "AT" restriction only. One deviation involved the message "AFTER PASSING [position] CLIMB TO [level]"—issued by voice. This voice phraseology, used by some states (e.g., Iceland), is used instead of "CLIMB TO REACH [level] BY [position]" to prevent the pilot from interpreting the clearance as "Climb to reach level *by way of* position". The frequency of this voice message in the North Atlantic is unknown.

In each of these errors related to a conditional clearance, the flightcrew missed the "AT" restriction and climbed early without clearance. In one error with UM 22 ("AT [position] CLIMB TO [level]"), the flightcrew used an abeam position instead of the correct latitude/longitude coordinates.

However, in this data set, there were only two LHDs associated with the "AT [time]" (UM 21) clearance and only one associated with the combination of UM 21 and UM 26. The most common single scenario associated with pilots climbing without a clearance in this data set was a pilot climbing after requesting (but not receiving) a clearance to climb.

Climbed late

In a handful of cases (5 out of 46 or 11%), the flight climbed late in response to a clearance. The fact that the majority of these (4 out of 5, or 80%) involved a conditional clearance is not surprising since the most commonly issued clearance is to "CLIMB TO REACH [level] BY [time]". One LHD involved UM 22 communicated by CPDLC; two LHDs involved UM 26 (one via CPDLC, the communication medium for the other was unknown). In the error involving UM 26 issued via CPDLC, the flightcrew was issued a route and level change (with the "BY [time]" restriction); the crew missed the level change and consequently climbed late. One LHD involved UM 27 ("CLIMB TO REACH [level] BY [position]"), the crew *began* the climb at the referenced position, rather than completing their climb by the position as cleared. Finally, one LHD involved a flightcrew that missed their level restriction.

Climbed without a clearance

In the bulk (43%, n=20) of LHDs attributed to pilot error, the flightcrew climbed without clearance. The causal factors related to these instances were varied. In six LHDs, the aircraft climbed to a requested, but not cleared, altitude—in one case, after the controller responded with "standby". Two LHDs involved the negotiation of flight levels between the pilot and controller: The controller asked "When can you accept [level]?" and the flightcrew responded "now" and erroneously climbed to that flight level without a clearance. In two cases, the flight overshot their cleared altitude. In one instance, an aircraft took an instruction (issued by voice) intended for another aircraft; in another, the flightcrew accidently rejected the climb clearance and then climbed. The causal factor of 11% of pilot LHDs (n=5) was not identified.

Descent Clearances

Twelve of the 46 LHDs in the NAT in 2017 were related to clearances to descend; none of these 12 involved a conditional clearance.

Descended early

Two LHDs involved aircraft that descended early; one where the flightcrew missed a time constraint (regarding a block altitude, issued via voice) and the other where the flightcrew missed a crossing restriction (issued via CPDLC).

Descended late

Three LHDs involved an aircraft that descended late. One involved difficulty with voice communication over the ocean, one involved an aircraft that failed to descend for an unknown reason, and one involved a flightcrew that missed a crossing restriction (issued via CPDLC) and descended late.

Descended without a clearance

Seven LHDs involved an aircraft that descended without a clearance. Three of these were related to weather deviations, in one case the flightcrew leveled below (i.e., undershot) their cleared altitude, one LHD was due to aircraft performance, and finally one involved confusion between several re-clearances (issued by CPDLC). In one case, no causal factor was identified.

Other

Three additional LHDs were related to erroneous position reports: two included a potential altitude error in the position report; the other was a position report that was delivered late.

Altitude Deviations in New York Oceanic Control Area

To supplement the analysis, we also analyzed 101 altitude deviations—reported in New York OCA—including NAT High Level Airspace (HLA) and the West Atlantic Route System (WATRS) and spanning January 2014 to June 2018. Of this data set, 89 of the reports were unique (that is, 12 reports contained duplicate information—referring to the same event).

Figure 6 shows the primary causal factor involved in the altitude deviations for the 89 unique reports. The bulk of reports (n=25) were related to ATC coordination, 23 reports involved a conditional clearance, 25 were related to weather, turbulence, or an emergency (in which the aircraft deviated from the cleared altitude using the captain's authority) and 8 involved confusion between one's clearance (or lack of clearance) and the flight plan. A handful (n=4) of altitude deviations did not provide enough detail to specify a primary cause.

Excluding the deviations related to weather (n=12), turbulence (n=6), an emergency (n=7), or a TCAS resolution advisory (n=1) deviations—28 of the remaining reports were attributed to Air Traffic Control error and 35 were attributed pilot error.

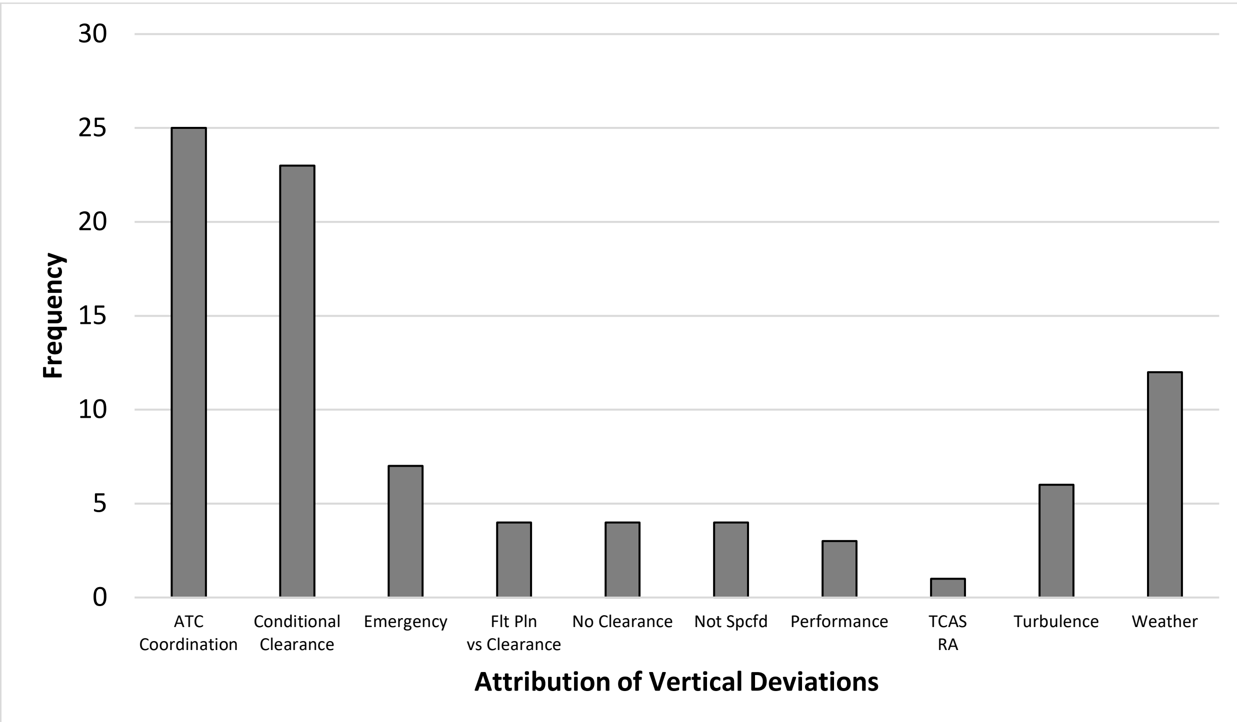

Figure 6. Distribution of causal factors of altitude deviations from the FAA (January 2014-June 2018).

Altitude Deviations Attributed to Pilot Error

There were 35 altitude deviations, from January 2014 to June 2018, reported by New York Center attributed to pilot error. The descriptions of these events (as submitted to the FAA) were analyzed to try to identify causal factors and error mitigation strategies. The distribution of deviations by communication medium—CPDLC or voice (i.e., high frequency [HF] or very high frequency [VHF]) is shown in Table 7. The majority of messages were communicated via CPDLC.

Table 7. Frequency of pilot altitude deviations by communication medium.

Communication Medium	Frequency
CPDLC	22
Voice	10
Unknown	3
Total	**35**

Each pilot deviation was further analyzed with regard to the resulting aircraft action —for example, whether the aircraft climbed or descended early, late, or without clearance—and any related factors—for example, whether a pilot request or conditional clearance was involved. Twenty-three of the deviations involved the communication of a conditional clearance (about 66%). The full distribution of pilot deviations, with outcomes and related causal factors, is shown in Table 8.

Table 8. Frequency of pilot altitude deviations by outcome and related factors.

Outcome and Related Factors	Frequency
Climbed early	**15**
AT [time] CLIMB to [level]	3
AT [time] CLIMB to [level]; CLIMB TO REACH [level] BY [time]	12
Climbed late	**4**
CLIMB TO REACH [level] BY [time]	4
Climbed without clearance	**7**
Confusion with re-clearances	1
Incorrect readback	1
Followed flight plan instead of clearance	2
Miscommunication related to clearance negotiation	1
Cleared by previous Center; failed to check into new Center	1
Military operation	1
Descended early	**3**
AT [time] DESCEND TO [level]	2
AT [time] DESCEND TO [level]; DESCEND TO REACH [level] BY [time]	1
Descended late (after requesting to climb)	**1**
DESCEND TO REACH [level] BY [time]	1
Descended without clearance	**1**
Aircraft performance	1
Other	**4**
Followed flight plan instead of clearance	1
CLIMB TO REACH LEVEL BY POSITION - Could not meet "BY" restriction due to aircraft performance	1
NORDO (loss of communication)	1
Non RVSM aircraft on RVSM clearance	1
Grand Total	**35**

Climb Clearances

Climbed early

In the bulk (43%, n=15) of altitude deviations attributed to pilot error, the flightcrew climbed early. In all but one of these instances the communications medium was identified as CPDLC (in the other, it was unknown). This is not surprising given the preponderance of climb, relative to descent, requests and clearances in this airspace. All of these deviations involved a conditional clearance: in 12 instances, the flightcrew received UM 21 and UM 26, "AT [time] CLIMB to [level] & CLIMB TO REACH [level] BY [time]"; in one of these instances the pilot reported only seeing the second page of the clearance. Three deviations in this category involved UM 21 without UM 26, "AT [time] CLIMB to [level]". For deviations that involved climbing early, the majority (14 out of 15; 93%) were known to have been communicated by CPDLC; in the other case, the communication medium (voice or CPDLC) was not identified. "MAINTAIN [current flight level]" UM 19, appeared to be included in 11 of the 15 instances.

Climbed late

In four instances (about 11%), the flight climbed late in response to a clearance. All of these deviations involved the conditional clearance "CLIMB TO REACH [level] BY [time]" – which is the most frequent conditional clearance in New York Oceanic airspace. Each of these clearances was communicated by CPDLC. In one instance, a clearance with a conditional time constraint that was no longer valid – the "REACH BY' time had already passed by the time it arrived on the flight deck.

Climbed without a clearance

In 20% of the altitude deviations attributed to pilot error, the flightcrew climbed without clearance. The causal factors related to these instances were varied. In two deviations, the flightcrew followed the flight plan instead of the clearance. There was one miscommunication related to clearance negotiation (e.g., the flightcrew was "under the impression" that they had received a clearance from the "last controller"). Other errors in this category involved confusion with re-clearances (n=1), an incorrect readback (n=1), a failure to check-in with a new Center (n=1) and an instance involving a military operation (n=1).

Descent Clearances

As mentioned earlier, clearances to descend are far less frequent over the ocean, where aircraft are continually seeking higher, more fuel-efficient, altitudes. Nonetheless, some deviations related to clearances to descend were reported by New York Center (5 out of 35; 14%). Four of these involved a conditional clearance.

Descended early

Three deviations involved aircraft that descended early; each of these involved a conditional clearance. Two deviations involved "AT [time] DESCEND TO [level]" and the one included both an AT and BY constraint: "AT [time] DESCEND TO [level] and DESCEND TO REACH [level] BY [time]".

Descended late

One deviation involved an aircraft that descended late involving the conditional clearance "DESCEND TO REACH [level] BY [time]" communicated by CPDLC.

Descended without a clearance

One deviation involved a descent without a clearance—the report states that aircraft was unable to maintain its assigned altitude and attributed it to aircraft performance.

Other

Four additional deviations were related to failing to take an action (either climb or descend). One was related to a flightcrew that missed a climb restriction ("CLIMB TO REACH [level] BY [position]"), due to aircraft performance, but ultimately descended. One involved the aircraft remaining at their current flight level—on the flight plan—rather than their cleared altitude (related to an error in the clearance and lack of readback), one involved a loss of communication between the flightcrew and ATC, and one involved a difference in performance between what was filed on the flight plan and the aircraft (non-RVSM aircraft on an RVSM clearance).

The FAA altitude deviation data also included one interesting example—with the same pattern as seen in the flightcrew errors—but actually attributed to ATC (and more specifically, the radio operator):

> *THIS IS A HEIGHT ERROR DUE TO THE INCORRECT CLEARANCE BEING ISSUED TO [FLXXX] BY THE ARINC RADIO OPERATOR. CLEARANCE ISSUED TO ARINC BY ATC WAS "AT [position] CLIMB TO AND MAINTAIN F430, CLIMB TO REACH F430 BY [position]". THE ARINC RADIO OPERATOR DID NOT DELIVER THE CLEARANCE VERBATIM. THE CLEARANCE ISSUED BY ARINC WAS "CLIMB TO REACH F430 BY [position]". [FLXXX] CLIMBED 4 MINUTES BEFORE EXPECTED. THERE WAS NO LOSS OF SEPARATION.*

This demonstrates the role of expectations in the use of conditional clearances is broader than the flightcrew. In this example, the radio operator also only communicated the *more frequent* message, and omitted the less frequent one—likely impacted by past experience in which only the second, more frequent message is communicated. Not surprisingly, in this case, the aircraft climbed early.

It should be noted that the clearances used in CPDLC are evolving and will continue to evolve in an attempt to minimize human error. The changes planned for future implementation, as of this writing, are described in Appendix C.

Comparison of Past and Present Data

The "AT [time] CLIMB TO [level]" (UM 21) message has long been considered a significant causal factor in altitude deviations as pilots acted on the clearance prematurely. Kraft (2014), however, found that there were more than twice as many LHDs associated with UM 21 *combined* with UM 26 than those associated with UM 26 alone, even though the most commonly issued conditional clearance by far was UM 26 "CLIMB TO REACH [level] BY [time]". Almost all of these errors occurred in ZNY airspace.

North Atlantic Region (NAT) Airspace (2017)

Kraft found that 55% of the LHDs attributed to pilot error in the ZNY airspace identified conditional clearances as a casual factor. Of these events, 61% (or 33% of all of the LHDs attributed to pilot error) were due to the UM 21 - UM 26 combination of clearances. In the 2017 NAT data obtained from the NAT CMA, only 20% of the LHDs attributed to pilot error involved conditional clearances; only one (in ZNY airspace) involved the UM 21 - UM 26 combination of clearances. In the 2017 NAT data obtained from the FAA / New York Center, three of the five (60%) LHDs attributed to pilot error involve conditional clearances. One of these three involved the UM 21 - UM 26 combination.

0 the use of UM 21 - UM 26 is on the decline is good, since its use should be discouraged. Ironically, it is the common use of UM 26 combined with the rare presentation of UM 26 preceded by UM 21 that is a contributor to the pilot 'missing' the UM 21 since they are seeing what they expect to see (the more common UM 26 alone). Using the 2017 data, we would expect one LHD per 600 transmissions of UM 21-UM 26 (with or without UM 19).

West Atlantic Route System (WATRS) Airspace (2016-2017)
The LHDs examined in WATRS airspace yielded very different results than the NAT airspace. The frequency and proportion of LHDs attributed to pilot error and associated with conditional clearances in 2016 in NY WATRS airspace was similar to what was found in the Kraft (2014) study. Recall that Kraft had found seven instances of LHDs attributed to the UM 21 - UM 26 combination of clearances over the four-year period. In an analysis of WATRS LHD data from 2016, the current study found that of the six LHDs attributed to pilot error in WATRS airspace, three (50%) were associated with conditional clearances. Of these, two involved the UM 21 - UM 26 combination of clearances; in both cases they were preceded by UM 19 (the instruction to maintain current altitude).

The 2017 data, however, tell a slightly different story. In 2017, there were 19 LHDs reported in the NY WATRS airspace, six of which were attributed to pilot error, but this included: two instances in which the aircraft was avoiding hazardous weather, one involving a TCAS RA, one was due to a missing position report due to radio failure, and one case in which the pilot neglected to inform ATC that they would not be able to comply with the altitude clearance due to aircraft performance. One of the six errors involved a conditional clearance that was clearly causal in the incident. In this case, the pilot requested a higher altitude, but was actually at the highest allowable altitude in that airspace. The controller issued a clearance to "AT [time] DESCEND TO [level]… DESCEND TO REACH [level] BY [time]" (UM 24 - UM 28) and the pilot descended early. While only a single event, it is further evidence of the error-prone nature of this type of combination of clearances. In this case, the pilot wanted to climb and ended up descending early. The underlying reason is similar "DESCEND TO REACH [level] BY [time]" (UM 28), is a more common clearance than the "AT [time] DESCEND TO [level]" (UM 24). It is understandable that a pilot might respond to the commonly seen "DESCEND TO [level] REACH BY [time]" clearance as they normally do, without 'seeing' the first condition.

Recommendations

Controllers maintain that the use of conditional clearances gives them the flexibility to accommodate pilot requests for altitude clearances that would be unavailable without them. While it would be technically possible for ground automation to hold altitude clearances and relay them when pilots can act on them, this option has not been explored due to its expected cost and technical complexity. Given that conditional clearances will be used, we propose the following recommendations.

Awareness of Hazards Associated with the Use of UM 21 ("AT") and UM 26 ("BY") in the Same Transmission

Pilots and controllers should be aware of the hazards associated with the use of UM 21 and UM 26. While it is recommended that controllers minimize the use of all conditional clearances whenever possible, use of UM 21 and UM 26 in same transmission is particularly problematic. When UM 21 is combined with UM 26 in the same transmission, the flightcrew must adhere to two restrictions regarding the level in the clearance. The first restriction is the time for starting the climb. The second restriction is the point at which the aircraft must reach the level in the clearance. Pilots are accustomed to receiving UM 26 and acting on it at will. On the rare occasion that it is preceded with UM 21, this restriction is too easily overlooked. While the frequency of use of UM 21 combined with UM 26 varies widely across centers, it is primarily used in NY oceanic airspace. When considering the frequency of use and the number of errors, there is a disproportionate number of pilot errors associated with this combination of messages in the same transmission.

Ensure Use of UM 19 ("MAINTAIN [level]") where needed

When UM 21 is sent alone, or when UM 21 is sent in combination with UM 26, it should be preceded by UM 19 ("MAINTAIN [level]"). We also recommend that UM 19 be issued in response to a pilot request (e.g., "WHEN CAN WE EXPECT…?") in addition to the response to the request whenever the requested altitude is not immediately available.

Flight Deck Standard Operating Procedures for CPDLC Message Review

Air carriers should examine their flightcrew training for CPDLC and incorporate standard operating procedures (SOPs) for CPDLC. To prevent error, both flightcrew members should silently and individually read the message from the flight deck display (see the see *the GOLD Manual*, ICAO Doc 10037). Pilots should also be aware of the shortcomings of one flightcrew member reading the CPDLC message aloud. If one pilot were to make an error while reading aloud (for example, misreading the word "AT"), the second pilot would not have an opportunity to catch that error. A recent review of a sample of CPDLC flightcrew training materials from seven airlines (Lennertz & Cardosi, 2015) found that only one carrier explicitly specified the procedure recommended in the *GOLD*; two carriers recommended a read-aloud procedure, and four carriers did not specify a procedure. While some messages are more important than others, flightcrews should not WILCO and act on a clearance that changes the trajectory of the aircraft before both pilots have read it in its entirety. (See Lennertz & Cardosi, 2015, for additional guidance on CPDLC training material for flightcrews).

Develop and Disseminate Guidance on Clearance Negotiation

The findings of this analysis suggest that additional guidance is needed for the *negotiation* of complex clearances (e.g., “WHEN CAN YOU ACCEPT…?”). In two of the analyzed LHDs, ATC asked the flightcrew when they could accept a higher flight level, and the flightcrew erroneously climbed to that higher level without clearance. In one case, ATC asked at what time the aircraft could accept Flight Level (F) 380. After responding, “able F380 anytime” via voice (HF), the aircraft immediately climbed without a clearance. In another instance, ATC asked what time the aircraft could accept F350 or F360. The aircraft responded “now” and then climbed without a clearance. In both of these cases, the pilots were asked (via CPDLC) “WHEN CAN YOU ACCEPT [level]”.

Use of the standard message “WHEN CAN YOU ACCEPT [level]” prompts the pilot of an equipped aircraft to respond with either a TIME or POSITION at which they can accept the altitude. In both of the pilot errors observed in 2017 with this clearance, the pilot responded via either HF or free text and climbed before any clearance was issued. The two LHDs described would likely not have occurred if the flightcrew had replied with a prompted downlink response, rather than free text or voice.

These errors indicate that the flightcrew misinterpreted this question as a clearance, in part due to the message format. Such negotiations will become more frequent, as NextGen technologies enable aircraft to more routinely modify their route of flight. Consequently, we recommend that controllers use the standard message element “WHEN CAN YOU ACCEPT [level]” (and not free text) when negotiating an altitude clearance via CPDLC. Pilots should be advised to reply with either standard response message “WE CAN ACCEPT [level] AT [time]/[position]” (and not free text) and to ensure that such negotiations are not interpreted as a clearance. In addition to inclusion in flightcrew training materials, such guidance should be added to the *GOLD*.

Another source of miscommunication with clearance negotiation involves the interpretation of the question “WHEN CAN YOU ACCEPT [level]”. To respond, the flightcrew must determine when the aircraft performance could meet the level restriction. In one error, the pilot responded to this inquiry with a time, but the clearance sent was not “AT [time] CLIMB TO [level]”, but rather, “CLIMB TO REACH [level] BY [time]”. It seems as though the pilot was indicating the time at which they could accept the clearance, but the controller interpreted the response as when the level could be reached. The interpretation of the inquiry and response needs to be explored and standardized, if needed.

Summary

Since 2000, ICAO has recommended that controllers minimize the use of conditional clearances (see *Human Factors Guidelines for Air Traffic Management (ATM) Systems*; ICAO Doc 9758). Since then, there have been several papers presented and discussions at ICAO meetings that echo the same sentiment. This research explored the magnitude of the effect of conditional clearances on LHDs in the NAT region and the incidence and effects of the UM 21 - UM 26 combination of clearances.

Our analysis of relevant ASRS reports observed that the most likely cause of the LHDs resulting from the

"AT [time]" and "CLIMB TO [level] BY" set of clearances is that the pilots overlook the first clearance (which they see occasionally) and only "see" the second (which they see much more often). The results of the communication and altitude deviation analyses generally replicated the findings of Kraft (2014), in which the vast majority of UM 21 and UM 26 combinations were sent from ZNY. While the contribution of this combination of clearances to LHDs has significantly decreased in the NAT airspace, it seems to be holding steady in WATRS airspace.

From a broader perspective, while the number of reported LHDs has declined over time, the proportion of LHDs involving conditional clearances remains comparable to the earlier data from US oceanic airspace (Kraft, 2014)—conditional clearances comprised 20% of the LHDs attributed to pilot errors reported by the CMA and 60% of 2017 errors reported by the FAA (from 2014-2018, conditional clearances were a factor in 66% of all FAA/ZNY altitude deviations). Conditional clearances remain the largest single identifiable factor contributing to LHDs attributed to pilot error.

We can expect, as new air traffic management procedures, such as Trajectory Based Operations, become available in the NextGen environment, the need to communicate complex clearances will rise. The use of conditional clearances adds to the flexibility of the use of the airspace, but also adds to the complexity of the pilot's task and opportunity for pilot error. A new issue that was identified in this analysis is one that is expected to increase in frequency in the future—that of clearance negotiation. Two of the LHDs involved pilots climbing after being asked, "When can you accept…?" When the pilots responded 'now', they erroneously interpreted this a clearance. In another instance, the pilot responded with the time that they could *accept* the clearance but then unfortunately accepted a clearance to be level at that time. With the expected increase in the use of clearance negotiation, guidance needs to be developed as to the best way to negotiate clearances while minimizing the probability of pilot or controller error.

References

Federal Aviation Administration. (2016). *The Future of the NAS*. Available: https://www.faa.gov/nextgen/media/futureofthenas.pdf

International Civil Aviation Organization. *Human Factors Guidelines for Air Traffic Management (ATM) Systems* (Doc 9758).

International Civil Aviation Organization. *Global Operational Data Link Manual (GOLD, Doc 10037, 1st Edition*), 2017.

International Civil Aviation Organization. *North Atlantic Operations and Airspace Manual* (*NAT Doc 007*), 2018.

International Civil Aviation Organization. *Procedures for Air Navigation Services—Air Traffic Management (PANS-ATM, Doc 4444, 16th Edition)*, November, 2016.

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

Lennertz, T., & Cardosi, K. (2015). *Flightcrew Procedures for Controller Pilot Data Link Communications (CPDLC)*. DOT-VNTSC-FAA-15-12.

North Atlantic Central Monitoring Agency (NAT CMA). http://natcma.com/ Accessed on 19 September 2018.

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.

RTCA DO-350, *Safety and Performance Standard for Baseline 2 ATS Data Communications, Initial Release (Baseline 2 SPR Standard) Volume I and II*, March 18, 2014.

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

Appendix A: Frequency of Conditional Clearances by Year and Center

Figures 7-9 show the total frequency of messages including “AT” and “BY” for each center, by year. Given the infrequency of some of the messages, the data are also provided in Tables 9 through 11, adjacent to each relevant figure.

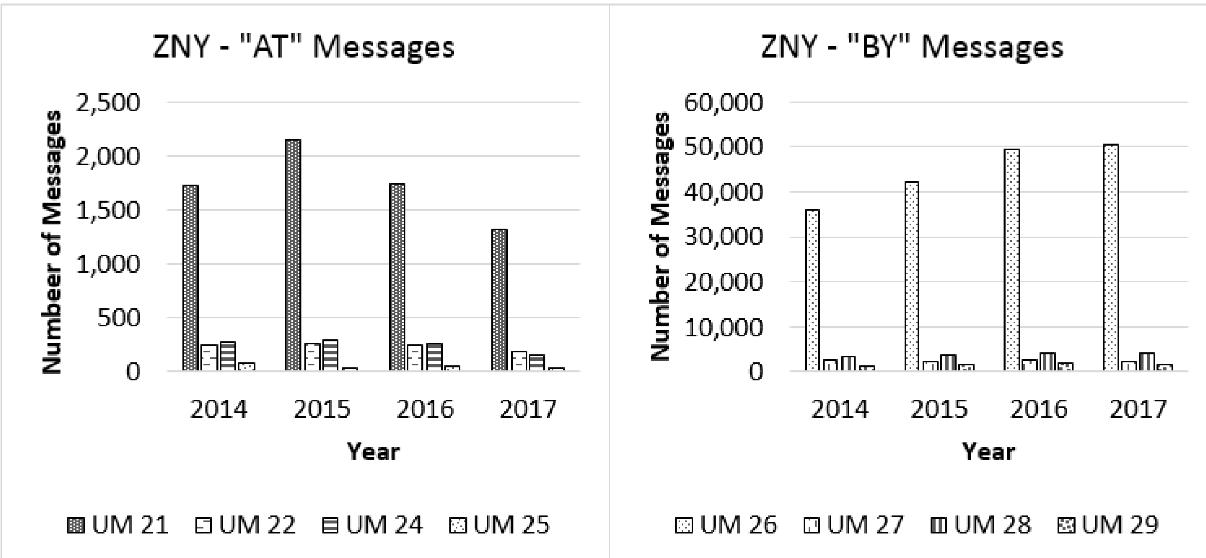

Figure 7. Frequency of “AT” messages (left) and “BY” messages (right) in ZNY, for 2014-2017.

Table 9. Frequency of messages, by year, at ZNY.

Message Number	2014	2015	2016	2017
UM 21	1,735	2,150	1,740	1,319
UM 22	242	265	253	190
UM 24	284	291	266	155
UM 25	77	33	48	36
UM 26	36,011	42,259	49,457	50,695
UM 27	2,822	2,423	2,775	2,243
UM 28	3,344	3,809	4,152	3,999
UM 29	1,322	1,429	1,833	1,677

As shown in Figure 7 and Table 9, UM 26 (“CLIMB TO REACH [level] BY [time]”) is the most frequently issued conditional clearance in ZNY airspace. Of the messages containing “AT”, UM 21 (“AT [time] CLIMB TO [level]”) was the most frequently issued message. On average, UM 26 comprised, about 15% of the total messages exchanged in ZNY. UM 21 comprised less than one percent of all messages exchanged.

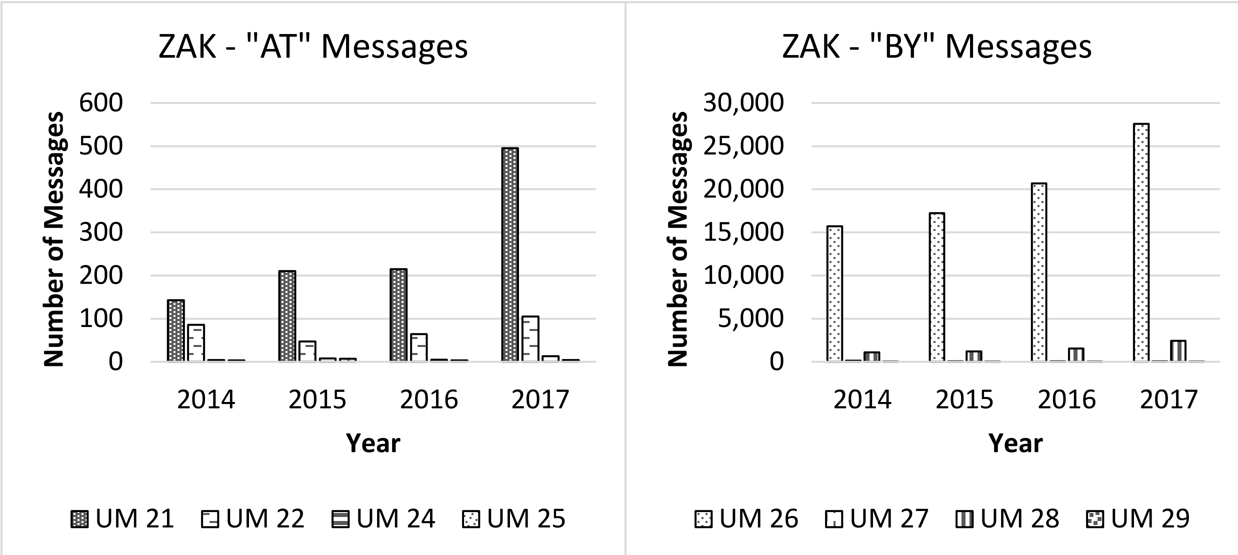

Figure 8. Frequency of "AT" messages (left) and "BY" messages (right) in ZAK, for 2014-2017.

Table 10. Frequency of messages, by year, at ZAK.

Message Number	2014	2015	2016	2017
UM 21	143	210	215	495
UM 22	86	47	64	105
UM 24	4	8	5	13
UM 25	3	7	3	4
UM 26	15,697	17,243	20,672	27,574
UM 27	133	60	66	59
UM 28	1,089	1,203	1,545	2,423
UM 29	8	11	17	21

As shown in Figure 8 and Table 10, UM 26 ("CLIMB TO REACH [level] BY [time]") is the most frequently issued conditional clearance in ZAK airspace. Of the messages containing "AT", UM 21 ("AT [time] CLIMB TO [level]") was the most frequently issued message. The frequency of these messages, however, is far less in ZAK compared to ZAN, despite the greater overall number of messages exchanged. On average, UM 26 comprised about 4% of the total messages exchanged in ZAK. UM 21 comprised 0.05% of all messages exchanged.

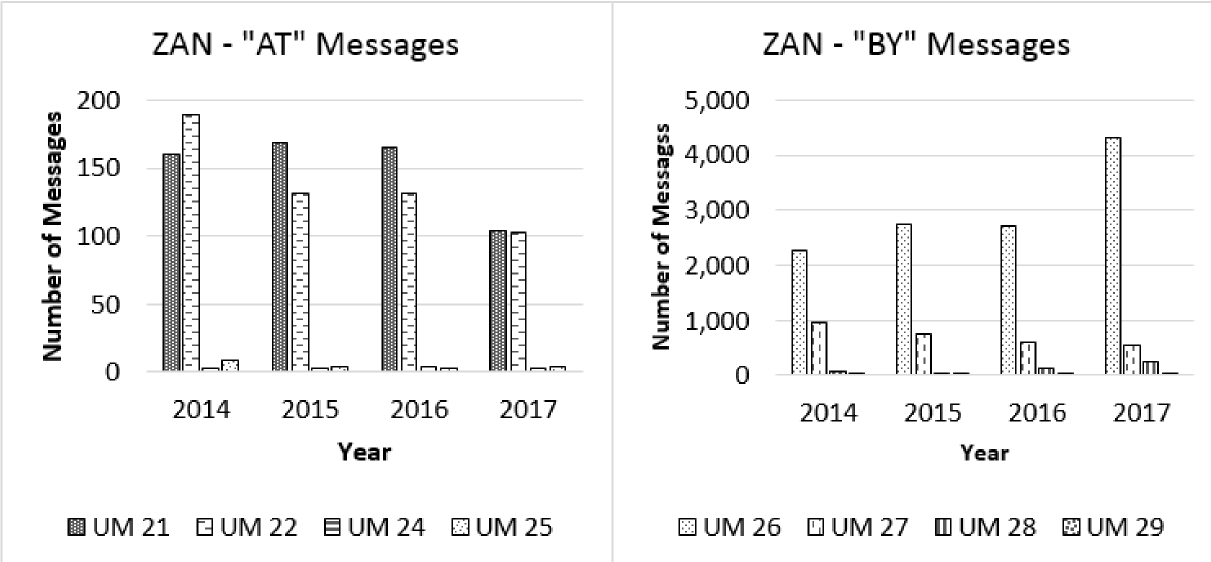

Figure 9. Frequency of “AT” messages (left) and “BY” messages (right) in ZAN, for 2014- 2017.

Table 11. Frequency of messages, by year, at ZAN.

Message Number	2014	2015	2016	2017
UM 21	160	169	165	104
UM 22	189	132	132	103
UM 24	3	3	4	3
UM 25	9	4	3	4
UM 26	2,254	2,741	2,714	4,313
UM 27	965	755	605	542
UM 28	85	11	135	241
UM 29	43	42	43	38

As shown in Figure 9 and Table 11, UM 26 (“CLIMB TO REACH [level] BY [time]”) is the most frequently issued conditional clearance in ZAN airspace—similar to what was observed in ZNY and ZAK. Of the messages containing “AT”, UM 21 (“AT [time] CLIMB TO [level]”) was the most frequently issued message, however, UM 22 (“AT [position] CLIMB TO [level]”) is a close second. ZAN has the lowest number of CPDLC messages exchanged, compared to ZNY and ZAK—likely reflecting the level of traffic in this airspace. On average, UM 26 comprised, about 2% of the total messages exchanged in ZAN. UM 21 comprised 0.10% of all messages exchanged.

Appendix B: Examples of Display of Messages in Current Implementations

Table 12 and Table 13 display a message dialogue on the flight deck with a UM 21 - UM 26 combination—for a Boeing 737 with a GE FMS and a Boeing 757/767 with a Honeywell Pegasus FMS, respectively. In both dialogues shown, the flightcrew requests a flight level (i.e., FL 310), receives an "UNABLE" from Air Traffic Control, followed by a UM 21 - UM26 combination. The images were obtained from the FAA's Data Comm Avionics Laboratory. In both examples, FANS 1/A implementation is shown.

Table 12. The implementation of a UM 21 and UM 26 combination on a Boeing 737.

<table>
<tr><th>Boeing 737 Example</th><th>Meaning</th></tr>
<tr><td>


</td><td>Aircraft sends a downlink request message, to climb to FL310</td></tr>
<tr><td>


</td><td>Aircraft receives an uplink message – with a UM 21-UM 26 combination

Message is shown on the first page</td></tr>
</table>

Boeing 737 Example	Meaning
	Response options to the message are shown on the second page
	This final page shows that the message was WILCOed by the flightcrew

Table 13. The implementation of a UM 21 and UM 26 combination on a Boeing 757 and Boeing 767.

<table>
<tr><th>Boeing 757 and Boeing 767 Example</th><th>Meaning</th></tr>
<tr><td>
</td><td>Aircraft sends a downlink request message, to climb to FL310</td></tr>
<tr><td>
</td><td>Aircraft receives an uplink message – with a UM 21-UM 26 combination

Message is shown on the first page</td></tr>
<tr><td>
</td><td>Response options to the message are shown on the second page</td></tr>
</table>

Boeing 757 and Boeing 767 Example	Meaning
	This final page shows that the message was WILCOed by the flightcrew

Appendix C: Revised Messages in New Implementations

Recently, RTCA SC-214 and EUROCAE WG-78 revised the wording of the messages (while retaining the operational intent) for future implementations (i.e., Baseline 2, RTCA DO-350A, 2016). These revisions were further incorporated into ICAO's *Procedures for Air Navigation – Air Traffic Management* (*PANS-ATM*; ICAO Doc 4444, 2016) and the *GOLD Manual* (ICAO Document 10037).

As shown in Table 14, for CPDLC messages that include a time restriction, it is recommended that future implementations spell out the word "TIME" to make the condition more noticeable and to prevent the flightcrew from acting on the clearance early. In CPDLC messages that include an action that must be completed by a time or positon, the condition has been further clarified to prevent misinterpretation, specifically "BY [time]" was modified to "BEFORE TIME [time]" and "BY [position]" was modified to "BEFORE PASSING [position]". Past errors indicate that flightcrews have misinterpreted the meaning of "by" and have initiated, but not completed before the specified time or position. This clarification aims to prevent these errors.

Table 14. Current (legacy) and future implementation of conditional clearance messages.

	Message Number	**Legacy Implementation** (per ICAO Doc 4444, 2007; FANS 1/A is shown in italics)	**Future Implementation** (per ICAO Doc 4444, 2016)
"AT"	UM 21	AT [time] CLIMB TO [level] *AT [time] CLIMB TO AND MAINTAIN [altitude]*	AT TIME [time] CLIMB TO [level]
	UM 22	AT [position] CLIMB TO [level] *AT [position] CLIMB TO AND MAINTAIN [altitude]*	AT [position] CLIMB TO [level]
	UM 24	AT [time] DESCEND TO [level] *AT [time] DESCEND TO AND MAINTAIN [altitude]*	AT TIME [time] DESCEND TO [level]
	UM 25	AT [position] DESCEND TO [level] *AT [position] DESCEND TO AND MAINTAIN [altitude]*	AT [position] DESCEND TO [level]
"BY"	UM 26	CLIMB TO REACH [level] BY [time]	CLIMB TO REACH [level single] BEFORE TIME [time]
	UM 27	CLIMB TO REACH [level] BY [position]	CLIMB TO REACH [level single] BEFORE PASSING [position]
	UM 28	DESCEND TO REACH [level] BY [time]	DESCEND TO REACH [level single] BEFORE TIME [time]
	UM 29	DESCEND TO REACH [level] BY [position]	DESCEND TO REACH [level single] BEFORE PASSING [position]

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