Flight Deck Human Factors Issues in Vertical and Lateral Deviations during North Atlantic Flight Operations

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***Abstract*—This paper describes analyses of vertical and lateral deviations in the North Atlantic (NAT) Region. We focus on events attributed to unintentional pilot error. We studied NAT deviations since this region already uses some of the capabilities envisioned under Trajectory Based Operations (TBO), such as Controller-Pilot Datalink Communications (CPDLC) and half-degree waypoint coordinates for latitude and/or longitude. Half-degree waypoints could be used for dynamic routes under TBO; CPDLC may be used to communicate this information.**

Our analysis of vertical deviations focused on conditional clearances, which require pilots to begin and/or end altitude changes upon specific conditions (either in time or position). CPDLC messages that restrict both when an altitude change can begin and by when it must be completed are especially prone to error. We analyzed brief descriptions of events from the NAT from 2017, and from the New York Oceanic Control Area from 2014-2018. Our analysis finds that similar errors are still occurring, particularly in New York West Atlantic Route Systems (WATRS) airspace. Although controllers are issuing fewer such conditional clearances, when they are issued, they are still resulting in vertical deviations.

Our analysis of lateral deviations focused on the use of half-degree waypoints without published names, and we also studied deviations in general. Unnamed half-degree waypoints can have ambiguous labels on flight deck displays, which might cause flightcrew errors. We examined 169 lateral deviations from 2017 and 68 events from 2018 to assess the magnitude of the issue and potential mitigations. We identified just six deviations with evidence of flightcrew issues related to waypoint display labels, three Gross Navigation Errors (GNEs), which are deviations greater than 10 NM, and three deviations under 10 NM.

Together, these analyses validate the effective flightcrew strategies identified in guidance documents for NAT and global operations published by the International Civil Aviation Organization (ICAO). We offer additional human factors recommendations to mitigate risk, such as design changes for flight deck systems. We also discuss potential considerations related to TBO.

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I. Introduction

There are several initiatives under the Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) Program Office designed to modernize air traffic management in the United States (US). One major initiative is the development of Trajectory Based Operations (TBO), an air traffic management concept that will "leverage improvements in navigation accuracy, communications, surveillance, and automation to decrease the uncertainty of an aircraft's path in four dimensions—lateral (latitude and longitude), vertical (altitude), and time—which will result in significant improvements in strategic planning." [1].

Some of the technologies necessary to support TBO, such as Controller-Pilot Datalink Communications (CPDLC), are already in use in the North Atlantic (NAT) Region. Also, for navigation, the NAT Region has "undesignated significant points," which are often called "unnamed waypoints." These waypoints are defined only by their latitude and longitude, and some of them use half-degree coordinates. Such waypoints could be building blocks for dynamic routes in TBO. In order to anticipate potential human factors issues with TBO in the US, the FAA is interested in learning more about how CPDLC and unnamed half-degree waypoints work in the NAT.

The purpose of these analyses is to identify causal and contributing factors for pilot errors related to vertical and lateral deviations in the NAT and to recommend mitigation strategies. Understanding these issues will facilitate the development of flightcrew standard operating procedures (SOPs) and training requirements to ensure effective and efficient human system integration with NextGen capabilities. We also consider recommendations for flight deck system design. We do not consider human factors issues related to TBO that impact air traffic controllers and Air Navigation Service Providers (ANSPs).

Here we first present background on NAT operations and how they compare with domestic operations. Next, we describe CPDLC conditional clearances and half-degree waypoints in more detail. Finally, we present our analyses and conclude with a summary and future considerations.

A. Background on NAT Operations

The International Civil Aviation Organization (ICAO) oversees the management of the NAT Region. The NAT High Level Airspace (HLA) is handled by ANSPs in Iceland (Reykjavik), Canada (Gander), Portugal (Santa Maria), US (New York Oceanic East), Norway (Bodø), and the United Kingdom (UK, Shanwick). The New York Oceanic Control Area (OCA) is divided into New York West Atlantic Route System (WATRS) and New York East, which is in the NAT.

Flying in the NAT has strict requirements for aircraft lateral and vertical navigation systems. Because air traffic surveillance (via radar or Automatic Dependent Surveillance-Broadcast, ADS-B coverage) combined with Very High Frequency (VHF) voice direct controller-pilot communication (DCPC) is not available for NAT operations, ANSPs use procedural control today. Under procedural control, aircraft must adhere to their cleared altitude and (lateral) route to reduce the risk of collision with other aircraft. Aircraft also provide Air Traffic Control (ATC) estimated times for reaching waypoints along the route. If the estimate is off by more than two minutes, the crew must inform ATC of a revised estimated time. Adherence to the planned route and timing is necessary both because communications between ATC and the flightcrew take more time in the oceanic environment, and because position reports from the aircraft are updated less frequently in comparison with operations over land. Also, over land there are direct voice communications between the active controller and flightcrew, but oceanic communications today are indirect. Oceanic communications may be via voice through an aeronautical radio station, by Aircraft Communications Addressing and Reporting System (ACARS) datalink, by CPDLC, or via voice with a land-based ATC facility on the boundary of oceanic airspace.

Within the NAT HLA is the Organized Track System (OTS), which resides primarily in the Gander and Shanwick oceanic control areas. The OTS is a set of air traffic routes (between Flight Levels 350 and 390) that connect North America and the UK/Europe. Flights in the OTS require CPDLC. The OTS routes are updated twice daily to optimize for winds. NAT operations are described in detail in NAT Doc 007 [2]. About 50% of flights in the NAT operate on the OTS routes, and the rest operate on more flexible “Random” routes, composed of individual named or unnamed waypoints [2]. Random routes may be issued when the aircraft flies above (or below) the OTS, or when the destination/origin is north or south of the OTS (e.g., routes between Spain and South America). Random routes may follow the OTS tracks for a part of the route, or they could be composed entirely of unique segments.

The NAT Region has an impressive safety record. There are plans to improve safety and efficiency even as traffic volume increases [3]. Adverse events such as vertical and lateral deviations are tracked by the NAT Central Monitoring Agency (CMA). The NAT CMA reviews vertical deviations greater than 300 ft (90 m) in altitude (known as *Large Height Deviations*, or LHDs), especially those that are “risk bearing,” meaning that there was a loss of separation between aircraft. In the lateral domain, the NAT CMA analyzes *Gross Navigation Errors* (GNEs), which are over 10 NM deviations from the cleared route, in detail. The NAT CMA also reviews lateral deviations of less than 10 NM, called *Interventions* if ATC acted to curtail the deviation, and *Preventions*, where ATC resolved the route discrepancy prior to an actual deviation. In 2017, there were 51 LHDs attributed to flightcrew error and 33 GNEs implicating flightcrew error across many thousands of flights [3]; so the overall rate of deviations is quite low. LHDs are the focus area for safety improvements in the NAT [3].

From a flightcrew perspective, procedural control is quite different from operations in surveilled airspace with DCPC via VHF voice. Crews need to be aware of when they enter or exit oceanic airspace, and they require additional training, checklists, and flight procedures for oceanic operations. Currently, they must request a clearance to enter oceanic airspace 30 to 90 minutes in advance (which may be while in flight) and then they may have to reprogram their Flight Management System (FMS) if there are revisions to their original (filed) flight plan route. Pilots also have to allow more time for communicating requests and receiving clearances to change altitude for fuel efficiency or ride quality, or to change their lateral route to avoid poor weather. This can be especially important because oceanic operations often happen overnight, when fatigue is a factor. Also, oceanic flights tend to last several hours with low workload, making it hard to stay alert. Crew training requirements and flight procedures are covered in [2]. Even with extensive guidance, there are variations between different operators in how they implement their SOPs.

B. CPDLC and Conditional Clearances

CPDLC is the preferred mode of conveying complex vertical and lateral clearances in oceanic airspace. CPDLC can support the communication of complex information. This information can typically be loaded into the FMS with fewer button presses than if communicated by voice.

In the near term, as air traffic increases over the ocean, so will the frequency of communications and negotiation. Pilots will ask about the availability of flight levels and controllers will query 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 or position, the controller may issue a vertical conditional clearance that allows the pilot to change flight level at a future time or position. Conditional clearances require careful review on the flight deck in order to avoid a vertical deviation.

CPDLC conditional altitude clearances 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 increases the complexity of the pilot’s task and, correspondingly, increases the opportunity for error. Some flight deck avionics may generate an automated reminder for the flightcrew when an action should be initiated (so that they do not begin it late) but no similar assistance exists to prevent the flightcrew from acting on the clearance early.

Conditional altitude clearances (shown in Table I) can include a restriction on the time or place for starting a climb or descent, and/or a place or time for when the altitude (i.e., [level]) is to be reached.

TABLE I. VERTICAL CONDITIONAL CLEARANCES [4].

CPDLC Uplink Message (UM) Number		*ICAO Message [6]*
AT	UM 21	AT [time] CLIMB TO [level]
	UM 22	AT [position] CLIMB TO [level]
	UM 24	AT [time] DESCEND TO [level]
	UM 25	AT [position] DESCEND TO [level]
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]

"CLIMB TO REACH [level] BY [time]" (CPDLC UM 26) is the most frequently used conditional clearance in the New York OCA. It is issued at least ten times more often than any of the other conditional clearances that are shown in Table I [4, 5], which lists messages from ICAO's Procedures for Air Navigation Services—Air Traffic Management (Doc 4444) [6]. Yet, in an analysis of risk-bearing LHDs [4], the combination of two messages "AT [time] CLIMB TO [level]" (UM 21) and "CLIMB TO REACH [level] BY [time]" (UM 26) was significantly more likely to contribute to the LHD than the use of "CLIMB TO REACH [level] BY [time]" (UM 26) alone.

Analysis of recent oceanic communication data showed that, from 2014 through 2017, the combination of UM 21 ("AT [time]…") and UM 26 ("…BY [time]") was most often sent by New York Oceanic Air Traffic Control Center (ZNY). It is used very rarely by Oakland Oceanic Air Traffic Control Center (ZAK) and Anchorage Oceanic Air Traffic Control Center (ZAN). In fact, in ZNY, when a UM 21 was sent, it was accompanied by UM 26 most of the time. For ZNY, in the majority of cases, the combination UM 21 - UM 26 was preceded by an instruction to maintain current altitude (UM 19, "MAINTAIN [level]"), but not always. About 4% of UM 21 - UM 26 combinations did not include UM 19 [5].

This combination of clearances in the same transmission instructs the flightcrew to comply with two restrictions. The first restriction is the place or time for starting the maneuver. The second restriction is the point at which the aircraft must complete the maneuver. While the frequency of this combination of clearances was found to vary widely across oceanic air traffic control facilities, the effect on LHDs was consistent—flightcrews maneuvered too early.

C. Half-Degree Waypoints

A typical OTS track begins with named (published) waypoints at the oceanic entry points (e.g., MALOT and LIMRI off the coast of Ireland), followed by undesignated waypoints (without published names) at different latitudes that cross the 20 West, 30 West, 40 West, and 50 West meridian (longitude) lines. The track ends with a named point (or points) as the aircraft transitions from oceanic to domestic airspace.

Within the OTS, there are many unnamed waypoints that have half-degree latitude waypoint coordinates; these are used to define tracks for Performance Based Communication and Surveillance (PBCS) routes. ATC can assign PBCS-qualified aircraft to fly along a track composed of only half-degree latitude waypoints; other tracks in the OTS are composed of only whole-degree waypoints [2]. PBCS operations allow ATC to space aircraft more closely since the tracks are just 30 NM apart in latitude.

In contrast to oceanic entry and exit waypoints, which have five-letter names, there is no common alphanumeric name for an undesignated waypoint's latitude and longitude coordinates in the aircraft navigation database and ANSP systems for these waypoints. While the aircraft navigation database does have an alphanumeric label that is shown on the flight deck displays, the ANSP systems define such unnamed waypoints only by their latitude and longitude coordinates.

Flightcrews could confuse unnamed half-degree waypoints with unnamed whole-degree waypoints due to non-standard and abbreviated naming conventions on flight deck systems [7] and such confusion could lead to a GNE. Table II lists different waypoint label conventions. The key mitigation to the potential for confusion about waypoint labels is for pilots to call up (i.e., expand) the waypoint's full coordinates when reviewing the routes programmed in the FMS.

TABLE II. CURRENT WAYPOINT LABELS THAT FLIGHTCREWS MUST MANAGE, ADAPTED FROM [8].

Source	**Example Waypoint Label**
NAT Track Message	50/50 (i.e., 50°/50°W) 5030/40 (i.e., 50°30'N/40°W)
ICAO Flight Plan Short Format (degrees only, 7 characters) [6]	50N050W
ICAO Flight Plan Long Format (degrees and minutes, 11 characters)	5000N05000W
7-Character FMS/Map Display after entry using full Latitude/Longitude	N50W050[a]
ARINC 424 Paragraph 7.2.5, for the NAT Region	5050N (i.e., 50°N/50°W) N5050 (i.e., 50°30'N/50°W)
ICAO NAT Region Bulletin [9] recommendation	5050N (i.e., 50°N/50°W) H5050 (i.e., 50°30'N/50°W)
Typical FMS LEGS page expanded coordinates	N5000.0 W05000.0 N5030.0 W05000.0
RTCA DO-258A [10] Future Air Navigation System (FANS) Interoperability Specification	500000N0500000W

a. Note that this label could represent either a whole degree waypoint or a half-degree waypoint.

D. Overview of Analyses

We used event summaries from the NAT CMA for both the vertical and lateral analyses. Note that ANSPs submit events summaries on a workload permitting basis. While they represent a large number of records, they are potentially incomplete, so they cannot be used to assess or compare the frequencies of different event types. They can, however, provide insights on causal factors related to the events.

Both analyses looked at data from the NAT CMA 2017. For the vertical deviations, we also looked at event summaries for pilot deviations reported in New York OCA (including both NAT HLA and WATRS) from January 2014 to June 2018. For lateral deviations, we again studied events from 2018. In addition, we studied the programmed route of the flight versus the cleared route for the lateral deviations. The data for the lateral deviations included operator explanations of the events in many cases. The operator input could provide us insights unavailable through position reports and other ANSP records—though it did not always provide a clear explanation because the crew might not remember the event clearly, or they might not have understood the issue as it happened.

All of the events we studied involved unintentional deviations attributed to pilots. We excluded intentional flightcrew deviations such as those for weather, turbulence, or emergencies, or deviations that were due entirely to ATC issues. We also removed events where contingency procedures (e.g., for weather deviations) were applied incorrectly.

We describe the analysis of vertical deviations first, then the analysis of lateral deviations. For each analysis we first describe the Scope, then the Method, Results, and conclude with a summary and future considerations.

II. Analysis of Vertical Deviations

Building on the past analysis by Kraft [4], we examined the safety occurrence data on LHDs in NAT from the ICAO NAT CMA to understand the interaction between pilot error and conditional clearances. To supplement this analysis, we examined pilot deviations in New York's airspace (including both NAT and WATRS).

A. Scope

Our analysis of vertical deviations focused on conditional clearances in the NAT. We wanted to compare data from 2017 to the past analysis by Kraft [4] to examine whether the combination of clearances—instructing the flightcrew to adhere to both an "AT" and "BY" condition—was still a factor in LHDs. We also wanted to assess the role of vertical conditional clearances in LHDs in general.

We studied 2017 event summaries of LHDs collected by the NAT CMA. In some, but not all, cases we could also determine whether the pilot and controller communicated via voice (e.g., High Frequency, HF, or VHF) or CPDLC. Note, the proportion of clearances communicated via voice and CPDLC in this airspace is not known. Our full analysis of this data is presented in [5].

B. Method

For the 2017 NAT CMA data, we reviewed the event description and classified the outcome of the event (i.e., whether the flightcrew climbed or descended early, late, or without a clearance). For each event, we analyzed the event to identify a primary causal factor—such as whether a conditional clearance or a pilot request was involved. For LHDs involving conditional clearances communicated by CPDLC, we further analyzed the specific messages involved (e.g., UM 21, UM 26). Note, in some cases, the description of the event was ambiguous and a primary causal factor could not be identified.

C. Results

1) LHDs in the NAT Airspace

We analyzed 46 LHDs attributed to pilot error reported in the NAT in 2017. The categorization of each pilot-attributed LHD, by outcome and identified primary causal factor, is shown in Table III.

Each pilot-attributed LHD was categorized with regard to the resulting outcome—whether the aircraft climbed or descended early, late, or without clearance, and any related factors, as shown in Table III. Of these, three were related to late position reports; in another seven, no causal or coincident factors could be identified. Of the remaining 36, nine (25%) involved conditional clearances.

a) Climb Clearances

In six of the LHDs attributed to pilot error, the flightcrew climbed early. Five of these events 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]". 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.

In each of these errors related to a conditional clearance, the flightcrew missed the "AT" restriction and climbed early without clearance. The most common single scenario associated with pilots climbing without a clearance in this data was a pilot climbing after requesting (but not receiving) a clearance to climb.

In five of the LHDs, the flight climbed late in response to a clearance. The majority of these (4 out of 5, or 80%) involved a conditional clearance. The bulk (43%, n=20) of LHDs attributed to pilot error were attributed to the flightcrew climbing without a clearance. The causal factors related to these instances were varied. In six LHDs, the aircraft climbed to a requested, but not cleared, altitude. Two LHDs involved the negotiation of flight levels between the pilot and controller: The controller asked "When can you accept [level]?" and the flightcrew essentially responded "now" (via free text) and climbed to that flight level without a clearance.

b) Descent Clearances

Only 12 of the 46 LHDs in the NAT in 2017 were related to descents. This is not surprising, since instructions to climb are more frequent in oceanic airspace, as aircraft seek to fly at higher, more fuel-efficient altitudes. None of these 12 involved a conditional clearance.

2) Altitude Deviations in New York OCA

To supplement the analysis, we analyzed 101 altitude deviations in New York OCA from January 2014 to June 2018. This included both the NAT and WATRS airspace. As with the NAT CMA data, each event summary was analyzed by communication medium (voice, CPDLC, or unknown), outcome, and primary causal factor.

TABLE III. FREQUENCY OF PILOT-ATTRIBUTED LHDS BY OUTCOME AND RELATED FACTORS (NAT EVENTS IN 2017).

	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 Communications	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**

Of 35 altitude deviations attributed to pilot error, 24 (68%) involved conditional clearances. Each pilot deviation was categorized with regard to the resulting action—whether the aircraft climbed or descended early, late, or without clearance, and any related factors, as shown in Table IV.

a) Climb Clearances

In the bulk (43%, n=15) of altitude deviations attributed to pilot error in the New York OCA, the flightcrew climbed early. 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]”. The majority of these deviations (14 out of 15; 93%) were communicated by CPDLC.

TABLE IV. FREQUENCY OF PILOT-ATTRIBUTED ALTITUDE DEVIATIONS BY OUTCOME AND RELATED FACTORS (NEW YORK OCA EVENTS 2014-2018).

	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
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
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**

In four deviations, the flight climbed late in response to a clearance. All of these deviations involved the conditional clearance “CLIMB TO REACH [level] BY [time]”.

In seven deviations, the flightcrew climbed without clearance; one of these was related to clearance negotiation (e.g., the flightcrew was “under the impression” that they had received a clearance from the previous controller).

b) Descent Clearances

Fourteen percent of the deviations (5 out of 35) in New York OCA related to descent clearances. Four of these involved a conditional clearance.

Three of these deviations involved aircraft that descended early: Two 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]”. One deviation involved an aircraft that descended late involving the conditional clearance “DESCEND TO REACH [level] BY [time]” communicated by CPDLC.

D. *Analysis of Reports Submitted to the Aviation Safety Reporting System*

To understand some of the human factors issues behind the vertical deviations, we analyzed reports related to vertical conditional clearances submitted to the Aviation Safety Reporting System (https://asrs.arc.nasa.gov/). Only a handful of reports were relevant to this analysis, but it appears that the most likely cause of the deviations resulting from the "AT [time]" and "CLIMB TO [level] BY" set of clearances is that the pilots overlook the first clearance (which they receive relatively infrequently) and only "see" the second (which they receive much more often). This may especially be the case if the flightcrew is expecting a climb clearance.

E. *Discussion*

This analysis of NAT airspace indicates that 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 [4]; conditional clearances comprised 20% of the LHDs attributed to pilot errors reported by the NAT CMA and 60% of 2017 errors reported by the FAA in ZNY. (From 2014 to 2018, conditional clearances were a factor in 66% of all ZNY altitude deviations.) Our results indicate that conditional clearances remain the largest single identifiable factor contributing to pilot error and that the use of "AT [time] CLIMB TO [level]" and "CLIMB TO REACH [level] BY [time]" *in the same transmission* is particularly problematic. While neither of these clearances results in an inordinate number of pilot errors when used on their own, the combination in a single transmission results in many more errors than either clearance when issued alone. Recall that the most commonly issued conditional clearance is to "CLIMB TO REACH [level] BY [time]" [4, 5]. In these cases, it appears as though the pilots are responding to the *very common* second part of the clearance (REACH [level] BY [time]) as they usually do, by climbing immediately and 'missing' the first part of the clearance (AT [time] CLIMB TO [level]).

The first proposal to mitigate the errors observed with "AT [time..] CLIMB…" clearances (UM 21) was proposed in a working paper presented at the NAT Air Traffic Management working meeting [11]. This paper proposed that any conditional clearance to change altitude in the future (i.e., "AT [time]" or "AT [position]") be preceded with an instruction to maintain current altitude (UM 19 "MAINTAIN [level]). This guidance was promoted by Kraft [4] and was published in the ICAO's *Global Operational Data Link (GOLD) Manual* [12]. The "MAINTAIN" message can provide an additional cue to crews that the new altitude clearance is not be acted on upon receipt. This, however, is not required in US airspace within the NAT [2] nor does it alleviate all errors associated with this message combination.

The use of "AT [time] CLIMB TO [level]" and "CLIMB TO REACH [level] BY [time]" in the same transmission should be discouraged. The best error mitigation strategy for this and any other complex clearance is for both flightcrew members to silently and individually read the message from the flight deck display and discuss the clearance before maneuvering the aircraft. This guidance is included in the GOLD Manual [11].

We can expect, as new air traffic management procedures, such as TBO, 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. The best use of CPDLC for complex messages and clearance negotiation needs to be understood to support the implementation of advanced NextGen concepts.

III. Analysis of Lateral Deviations

A. *Scope*

Our first priority was to study lateral deviations that involved half-degree waypoints and their display labels. We studied 2017 event summaries and events from the first half of 2018. We wanted to assess the magnitude of the problem and identify potential mitigation strategies for reducing or eliminating lateral deviations that may be enabled by the flight deck waypoint labels. We began by identifying events with half-degree waypoints in either the cleared route or the flight planned route. To put these events in perspective, we also looked at general patterns for lateral deviations regardless of whether the aircraft was operating on or off the OTS, and regardless of whether the route used partial- or whole-degree waypoints. We considered all types of lateral deviations (GNEs, Interventions, and Preventions), but the NAT CMA data was most complete for GNEs and Interventions.

One limitation of this analysis is that we cannot determine whether the frequency of deviations involving half-degree waypoints has changed over time because we do not know either the exposure rate (how often they were issued), or the number of lateral deviations that occurred (how often there were deviations). A second limitation is that we cannot know what a crew saw on their flight deck displays when a lateral deviation occurred, especially in terms of waypoint display labels. This is not just a limitation of the information available about the event. In fact, flight deck displays vary in many ways (e.g., size, resolution, number of characters displayed, display formats, data displayed, and the user interface). The variation is a function of both the display hardware and the avionics software. Even within a given aircraft fleet for a given operator, different aircraft may have different display capabilities or software versions.

We are preparing a full technical report on the lateral deviations. The report includes a review of literature and an exploration of NAT flight deck procedures used by different operators. Here we present a summary of the analysis of lateral deviations; additional details will be provided in the full report. The literature review in the full report looks at flight deck human error, particularly related to FMS data entry. We also review literature on the naming convention for the National Reference System (NRS) grid of waypoints, which are in the high altitude airspace over the Continental US. Those studies may inform the development of any naming convention proposed for the NAT Region, should that be considered. The full report also summarizes findings from conversations with several operators about their flight deck procedures related to route reviews and lateral deviations.

B. Method

We preprocessed the 2017 data by trying to classify each event in as much detail as we could, but sometimes the description was ambiguous. In these cases, we ascribed up to three possible causes. We also determined what types of waypoints were involved in the event (half-degree, whole degree, named, or unnamed) and made a judgement about whether the event could be attributed to unintentional pilot error. The data from 2018 was preprocessed by the NAT Scrutiny Group; we used their determination of whether the event was attributed to pilot error. Review by the NAT Scrutiny Group was also helpful in clarifying the event descriptions prior to analysis.

In cases where we determined that there was evidence of a waypoint display label factor, the operator responses either specifically called out the waypoint display label as a factor, or the error was confirmed after the crew expanded the waypoint coordinates (after an ATC request).

The event data was considered insufficient to determine whether waypoint display labels were a factor if (a) there was no operator response and/or insufficient information in the other event materials to know whether the pilot ever looked at the waypoint labels, or (b) it was unclear whether the pilot ever attempted to review the route on the FMS.

The event was determined to be unrelated to waypoint display label if:

- The crew stated they did not notice that the lateral route was revised by ATC.
- The crew stated they did not load the revised clearance.
- Some half- or partial-degree waypoints were correctly entered, but one was not.
- The first two digits of the incorrect waypoint longitude or latitude were different between the whole and half-degree waypoints. For example, if the observed aircraft route went through a waypoint at 6230N latitude, but neither the original flight plan nor the revised route had a 62N position.
- Equipment failure on the flight deck kept the crew busy, so they were unable to enter revised clearance prior to deviation.
- Crew stated they mis-entered a digit in the waypoint coordinate.

C. Results

After preprocessing the 2017 data, we identified 169 events that involved unintentional lateral deviations attributed to pilots. The data from the first half of 2018 included 68 reports with complete records, but we also reviewed summaries of the data from the latter half of 2018. Overall, events related to waypoint display labels are a small subset of the events with flightcrew errors; we found just 9 such events in 2017 and 11 in all of 2018. The bulk of flightcrew errors were related to route revisions, waypoint updates, or other issues that have previously been identified [2].

1) Half-Degree Waypoints

There were 20 events where unnamed half- or partial-degree waypoints were present in either the cleared route or the programmed route. Of these, there were just six that had evidence of issues with the waypoint display label, three GNEs and three Interventions. Of the GNEs, two (both in 2017) had half-degree latitude waypoints. The other GNE (from 2018) had a partial-degree waypoint, 61°40’ North at 40° West, which should have been entered as 61° North at 40° West. This type of error, where the longitude digits are inserted as minutes to the longitude has been seen before [8]; it is called the “double-longitude waypoint insertion error.” The three Interventions with evidence of a waypoint display label issue were all in 2018, and had half-degree latitude waypoints. Given only six cases with sufficient evidence for evaluation, we could not establish a pattern for human factors issues associated with half-degree waypoints and their labels.

2) Lateral Deviations in General

Of the 68 cases from January to June 2018, only one was on the OTS while the other 67 cases were on Random routes. This parallels the 2017 data, where just 20 of the 169 events in the set were on OTS routes. That is, the vast majority of lateral deviations occur on Random routes, not the OTS.

The 6-months of 2018 data included 32 Preventions, 20 Interventions, and 16 GNEs. Sixty of the 68 events, the vast majority, involved commercial flights. Six were with private operators and two were military flights. We looked at events based on the communication method for the clearance, but there was no trend in Preventions, Interventions, and GNEs as a function of the clearance delivery method. Lateral deviations can occur with any clearance delivery method.

Some observations from all the lateral deviations are that:

- Revised route clearances are a risk factor. There can be errors when entering or verifying new routes or updated waypoints.
- Both named and unnamed waypoints are involved in lateral deviations. The waypoint display label is not the only reason why incorrect waypoints are entered.
- Often, the route programming and clearance discrepancies are “small” and may therefore be harder to detect (e.g., a change to just one digit). In the first half of 2018, 48 of 68 events involved just *one* discrepant waypoint. Of these, one in three were named waypoints, two in three were unnamed.
- Named waypoints are associated with a lower rate of GNEs than unnamed waypoints. Three of 18 events with named waypoints became GNEs, but 13 of 44 events with unnamed waypoints became a GNE.

D. Discussion

Lateral deviations involving half-degree waypoints are a small fraction of the overall number of lateral deviations attributed to pilots in the available data. More common errors have already been documented (see [2]), and these include events where the flight plan route (or a portion of it) was flown instead of the cleared route, or events where waypoints were inserted incorrectly when pilots received a revised clearance.

We could not establish a pattern to deviations related to half-degree waypoints and their display labels, and as a result, we do not have a specific strategy for mitigating errors related to waypoint display labels. Flightcrew procedures for reducing lateral deviations are well addressed in [2], which provides guidance for preventing and catching errors related to waypoint display labels for half-degree waypoints, as well as other types of lateral deviations.

The key mitigation for display label ambiguity is for flightcrews to expand waypoint coordinates for all unnamed waypoints [2]. Flightcrews should not rely upon the waypoint label alone during route verification. NAT Doc 007 [2] also describes and promotes several flightcrew procedures designed to mitigate lateral deviations (see Chapter 8, "NAT HLA Flight Operation & Navigation Procedures," Chapters 14, "Guarding against Common Errors" and Chapter 15, "The Prevention of Lateral Deviations from Track"). These materials include checklists for pilots (including private pilots) and dispatchers. Section 8.3.12 of [2] discusses the strategy for coordinating manual entry of waypoint data into navigation systems by two persons working in sequence and independently. Section 8.3.14 discusses how flightcrews should recall and check the accuracy of inserted waypoints, independently for cross-checking. Such checks are designed to reduce the risk of confirmation bias (i.e., seeing what is expected rather than what is actually displayed). To improve the verification of revised route clearances, [2] recommends that when a revised clearance is received, the flightcrew should treat it "virtually as the start of a new flight" and employ all the procedures they would at the start of a new flight (Paragraph 8.4.7, [2]).

Unfortunately, these recommended strategies are repetitive and take time in practice. Expanding waypoint coordinates can be cumbersome because there are many waypoints to expand, because each waypoint's coordinates are expanded multiple times, and because some FMSs require several key strokes to call up the full waypoint coordinates. And errors in waypoint coordinates are rare, so most of the time, when the strategies are used, pilots find no errors, making this a vigilance task, which is hard for humans to do consistently over time. Also, the strategies for error mitigation are not always easy to implement in real situations. Pilots become task saturated or are interrupted from completing planned tasks. For example, an initial data entry error (perhaps just a single digit) might go uncaught even as pilots cross check and verify the route. Time pressure, distractions, fatigue, and many other operational factors play a role in lateral deviations. Errors of human fallibility, such as slips, transposition errors, and possibly the "double-longitude waypoint insertion error" (described above) will be difficult to eliminate. Confirmation bias (seeing what is expected) is another reason that cross-checking can fail, even with multiple concentrated reviews. Although some may see this as a failure of the pilot to do his/her job, this view disregards normal human variation in task performance.

We considered two other categories of mitigation strategies. First, the flight deck system design could be improved. A key improvement would be to make it easier for flightcrews to expand waypoints (e.g., fewer keystrokes). Some FMSs require five or more keystrokes to call up the full waypoint coordinates, while others require just two steps. Each waypoint must be called up one at a time; all waypoint coordinates cannot currently be expanded with one command. Given that pilots are asked to expand the coordinates many times, for many waypoints, reducing the number of required key strokes would be helpful. Another strategy to consider is to improve the ARINC 424 Paragraph 7.2.5 naming convention so that it is clearer to pilots. However, it may be difficult to do this without increasing the number of characters in the label. Another, more complicated, option is to develop flight deck software to compare and verify the cleared route sent by ATC against the route programmed in the FMS. Such a check exists in ground-based software, which can compare the FMS route obtained through a downlink message (DM 40) in response to an ATC query via UM 137 (confirm assigned route). The software alerts the controller if there is a discrepancy. This solution would be more involved because the avionics would need a good link to the ATC clearance, but it could improve the chances of the flightcrew detecting a discrepancy.

A second proposed strategy for mitigating errors related to display waypoint labels is to name all waypoints and publish these names in the navigation database. Based upon a review of studies on the naming convention for the NRS waypoints in the US, however, we found that this is a complicated proposal. There are many criteria that need to be met and validated by multiple stakeholder groups. Training would be required, and aircraft navigation databases would need to be large enough to store the new data. A concern would also be that the new names, if not well vetted, could create other types of errors. We discuss these issues in further in the full report to be published.

IV. SUMMARY

In this paper, we presented results of our analyses on lateral and vertical deviations in the NAT that were related to CPDLC and unnamed half-degree waypoints. These deviations are of interest to the FAA because their underlying human factors causes may have implications for future operations.

CPDLC, in particular, will be used to communicate and negotiate complex clearances in TBO. Our analysis of vertical deviations focused on CPDLC conditional clearances, particularly those with conditions that constrain both when a pilot can begin an altitude change and by when the change must be completed. We found that such CPDLC conditional clearances are prone to pilot error. 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 vertical deviations; pilots act on the (more common) second clearance without 'seeing' the first (less common) clearance.

Half-degree waypoints, which could be used in TBO dynamic routes, might also be more complex for pilots, especially when routes are revised. However, our analysis of NAT CMA data found just six lateral deviations that could be traced to half-degree waypoint labels over a two year period from 2017 through 2018. Pilot guidance for reviewing oceanic route clearances explicitly recommends that they expand the waypoint coordinates for all waypoints in the clearance. The guidance also recommends independent review by each pilot.

These flightcrew procedures appear to be effective in catching FMS programming errors related to half-degree waypoints, but they do involve many steps.

One limitation of our analyses is that our data cannot tell us whether the rate of deviations related to half-degree waypoints is changing over time. We do not know how often ATC issues routes with half-degree waypoints, and we do not know the full number of those routes that have lateral deviations. A similar limitation applies to the data on conditional clearances.

Our analyses confirm the value of the flightcrew procedures identified in NAT Doc 007 [2] and ICAO Doc 10037 [12]. For conditional clearances, and any other complex clearance, both flightcrew members should silently and individually read the message from the flight deck display and discuss the clearance before maneuvering the aircraft. For unnamed half-degree waypoints, the flightcrew should expand waypoint coordinates and independently review the route as well. We recommend that this guidance, currently included in ICAO material, be incorporated into pilot training programs as appropriate.

V. Future Considerations

We also considered how our findings could apply to NextGen in the US. One suggestion is that the use of conditional clearances for altitude changes should be minimized.

In terms of lateral routings, we note that pilots flying domestic US operations today do not expand coordinates for named waypoints, and unnamed waypoints are rarely, if ever, used. A question remains as to whether pilots will need to expand waypoint coordinates for TBO routes. TBO routes might well be based off a grid of waypoints with many more waypoints than currently in common use in the US airspace. We know that the NRS grid of waypoints has not been easily adopted for a variety of human factors and technical reasons. So the question remains as to how FMSs and navigation databases will handle a potentially large number of new waypoints. If a new naming convention is required, that will be a significant area for development and evaluation.

Another interesting finding of our analysis of lateral deviations is that deviations are more common for Random routes. Random routes are more desirable for operators in theory because they offer more flexibility than routes on a track system, even a dynamic one. However, there may be an increase in ATC route revisions for Random routes, which could result in a higher potential for lateral deviations. It is important to further understand why Random routes in the NAT are more prone to lateral deviations so that a similar pattern of error does not occur under TBO.

Finally, it is important to consider how to monitor and assess the performance of TBO in terms of adherence to cleared routes. Under procedural control in oceanic operations, adherence to the ATC route clearance is extremely important. With more timely surveillance and communication over land, lateral and vertical deviations might be detected earlier, but we must minimize their occurrence by giving flightcrews the best possible tools, procedures, and system checks.

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