Flight Deck Human Factors Issues in Lateral Deviations during North Atlantic (NAT) Flight Operations

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13. ABSTRACT (Maximum 200 words)
This study examines reported lateral flight path deviations related to the use of half-degree waypoint coordinates in the North Atlantic (NAT). Such waypoints can have ambiguous display labels on flight deck displays, which might result in flightcrew errors. We explored the magnitude of the issue and potential mitigations. We also reviewed literature related to flight deck data entry for route entry and verification. This included a review of studies about naming conventions for the United States National Reference System (NRS), which is a grid structure similar to that used over the NAT. We then analyzed lateral deviations reported in the NAT from 2017 through June of 2019. We only found eight deviations that had evidence related to waypoint display labels: three deviations greater than 10 NM and five deviations under 10 NM where Air Traffic Control intervened to prevent a larger deviation. Guidance documents for NAT operations already explain effective flightcrew strategies for preventing lateral deviations. We have no further flight deck procedure recommendations. We do, however, explore benefits and cautions related to other potential mitigations. We also discuss potential implications for Trajectory Based Operations (TBO) in the United States, since TBO may make use of half-degree waypoints.

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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

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Acronyms

Abbreviation	Term
ACARS	Aircraft Communications Addressing and Reporting System
ACN	Report ascension number in the ASRS database
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATSB	Australian Transportation Safety Board
ANSP	Air Navigation Services Provider
ASR	Annual Safety Report
CDU	Control and Display Unit
CMA	Central Monitoring Agency
CONUS	Continental United States
CPDLC	Controller-Pilot Data Link Communication
DCL	Departure Clearances (via CPDLC)
DCPC	Direct controller-pilot communication
DL	Data Link
DLM	Data Link Mandate
DM	Downlink message (CPDLC)
EFB	Electronic Flight Bag
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FIR	Flight Information Region
FMS	Flight Management System
FL	Flight Level
GNE	Gross Navigation Error
HF	High Frequency
HLA	High Level Airspace
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IRS	Inertial Reference System
LNAV	Lateral navigation
NASA	National Aeronautics and Space Administration
NAT	North Atlantic
FDPEOCR PT	Flight Deck Procedures and Ergonomics for Oceanic Clearances and Re-Clearances Project Team
NextGen	Next Generation Air Transportation System
ND	Navigation display
NM	Nautical mile
NRS	National Reference System
OFP	Operational Flight Plan
OTS	Organized Track System
PF	Pilot flying
PM	Pilot monitoring (not flying)
PBCS	Performance-based Communication and Surveillance

Abbreviation	Term
RLatSM	Reduced Lateral Separation Minima
RNAV	Area Navigation
SB ADS-B	Space Based ADS-B
SG	Scrutiny Group
SMS	Safety Management System
SOP	Standard operating procedure
TEM	Threat and Error Management
TMI	Track message identification (sequential number for the day of the year)
UK	United Kingdom
UM	Uplink message (CPDLC)
US	United States
VHF	Very High Frequency
VNAV	Vertical navigation

Preface and Acknowledgements

This document was prepared for the Federal Aviation Administration (FAA) NextGen Human Factors Division (ANG-C1), the Office of Aviation Safety (AVS), and the Flight Technologies and Procedures Division (AFS-410 Section B) under FB71, which is the Master Project for the FB71C1 and FB71C2 Interagency Agreements (IAAs). Work on this report was funded via the FY17 RE&D System Development—NextGen Air/Ground Integration PLA, Task 5. This report was funded by RF396, SF396, and TF396 under FB71C2 and by SE563, RE563, SE564 and RE564 under FB71C1.

FB71 is titled *NextGen Human Error Prevention and Mitigation Strategies for Trajectory-Based Operations*. This project examines the human-system performance risks, limitations, and opportunities associated with the use of unnamed partial-degree waypoints, focusing on flight operations in the North Atlantic (NAT). The goal is to help the FAA develop recommended mitigations to optimize human-system performance when using unnamed partial-degree waypoints. This work contributes to a NextGen Operational Improvement on Dynamic Required Navigation Performance (RNP), OI 108215-04.

Many other Volpe staff contributed to this report including Tracy Lennertz, Kim Cardosi, and Alan Yost. We thank the FAA for sponsoring this research and for providing technical guidance. Dr. Kathy Abbott and Kevin Kelly were the technical sponsors for this research. Chuck Perala and Karl Kaufmann were the program managers. We also thank the NAT Central Monitoring Agency and the International Civil Aviation Organization (ICAO) NAT Scrutiny Group for their assistance and expert insights.

Executive Summary

This research examines flight deck human factors issues related to lateral route deviations in the North Atlantic (NAT) High-Level Airspace (HLA). The Federal Aviation Administration (FAA) is concerned that lateral deviations may be more prevalent when the route has unnamed waypoints with half-degree latitude coordinates. Because of limitations in flight deck display capabilities, pilots may see ambiguous waypoint display labels for waypoints with half-degree coordinates, which might cause flightcrew errors that result in lateral deviations. The use of half-degree waypoints may increase under Trajectory-Based Operations (TBO), which are part of the Next Generation Air Transportation System (NextGen). TBO will have dynamic routes that may use half-degree waypoints for increased flexibility.

We begin this report with background on NAT operations, flightcrew tasks, waypoint label variability, and potential flightcrew errors that might be related to waypoint labels. Next, we present the three main components of this research: a review of related literature, analysis of lateral deviations, and a review of flight deck procedures. Finally, we summarize and discuss the implications of this work.

The literature review is focused on flight deck errors related to the entry and review of route data into the Flight Management System (FMS). Pilots must enter the route correctly and verify it to prevent lateral deviations. We also summarize findings from human factors studies of the waypoint naming convention for the National Reference System (NRS), a grid of high altitude waypoints over the Continental United States (CONUS) similar to the grid of unnamed waypoints in the NAT. These studies provide insights into how a new waypoint naming convention could be tested and validated if necessary.

Next, we present our analysis of reported lateral route deviations in the NAT. These data were gathered by the NAT Central Monitoring Agency (CMA). We studied events from 2017, 2018, and the first half of 2019 to identify causal factors for flightcrew errors and to identify potential mitigation strategies. We began by focusing on events with half-degree waypoints in either the cleared route or the flight planned route, and then expanded the effort to look at more general patterns for lateral deviations. Overall, events related to waypoint display labels are a small subset of the events with flightcrew errors. The bulk of flightcrew errors are related to route revisions and waypoint updates.

Out of the 24 reported deviations in our dataset where half- or partial-degree waypoints were involved, only eight that had evidence of confusion with the waypoint display label; three Gross Navigation Errors (GNEs), which are deviations of 10 nautical miles (NM) or greater, and five Interventions, where Air Traffic intervened to prevent a GNE. Given only eight cases with sufficient evidence for evaluation, we could not establish a pattern for human factors issues associated with half-degree waypoints.

Lastly, we present feedback from a few operators about their NAT flight deck standard operating procedures. The International Civil Aviation Organization (ICAO) and FAA offer guidance on how pilots should check oceanic route clearances, but how operators implement this guidance can vary.

We sought to identify ways of preventing and mitigating lateral deviations produced by the use of ambiguous waypoint display labels for half-degree waypoints. We conclude that many effective mitigations are already in place, such as the guidance for flightcrews to expand waypoint coordinates. The remaining lateral deviations may occur when pilots do not follow the recommended strategies. We consider why that may happen. We also explore how our findings might be generalized to TBO.

1 Introduction

Volpe Center is tasked with studying flight deck human factors issues that may be the cause of lateral deviations for flights operating in the North Atlantic (NAT) High-Level Airspace (HLA), with a focus on operations in the Organized Track System (OTS). Figure 1 illustrates the geographic areas of the NAT HLA. NAT flight operations have strict requirements for aircraft lateral and vertical navigation, as well as strict requirements for communication with the Air Navigation Services Provider (ANSP). The International Civil Aviation Organization (ICAO) oversees the management of the NAT Region, which is handled by ANSPs in Iceland (Reykjavik), Canada (Gander), Portugal (Santa Maria), United States (New York Oceanic East), Norway (Bodø), and the United Kingdom (UK, Shanwick). In altitude, the HLA includes Flight Level (FL) 285 through FL420. The OTS primarily resides in the Gander and Shanwick airspaces. The OTS contains defined routes for flights between North America and the UK/Europe at altitudes between FL350 and FL390. The OTS routes change twice daily to optimize for wind patterns.

Most waypoints in the NAT oceanic airspace are "undesignated significant points," which are unnamed. Figure 2 shows such points along example tracks. The yellow squares along the 20 West, 30 West, 40 West, and 50 West meridian (longitude) lines are undesignated significant points. In contrast to the named oceanic entry and exit waypoints (e.g., MALOT and LIMRI off the coast of Ireland), 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 display, the ANSP systems define such unnamed waypoints only by their latitude and longitude coordinates. Unnamed half-degree waypoints (with latitude or longitude coordinates at 30 minutes) are not often used outside of the OTS[1], but unnamed whole-degree waypoints are used throughout the NAT HLA.

Half-degree latitude waypoints were used in the Reduced Lateral Separation Minima (RLatSM) trial in the OTS from late 2016 until March 2018. In RLatSM, there was one track composed of half-degree latitude waypoints and this was paralleled by a whole-degree latitude track to the north and a whole-degree latitude track to the south. Today half-degree latitude waypoints are used in Performance Based Communication and Surveillance (PBCS) trial. The PBCS trial supersedes and replaces the RLatSM trial (ICAO NAT Ops Bulletin 2018_004, 2019a).

As with RLatSM, PBCS routes have parallel tracks that can be separated by just 23 NM; this separation results from defining a track based on half-degree latitude coordinates that lie in between parallel tracks defined by whole-degree latitude coordinates. After March 2019, PBCS routes may have more than one track based on half-degree waypoints, expanding the use of half-degree waypoints beyond the RLatSM trial. Because it takes only a few minutes to fly several miles in oceanic flight, there is less room for error with tracks separated by just 23 NM than with whole-degree tracks, which are separated by 60 NM. To date, all PBCS tracks are composed of either half-degree latitude coordinates or whole-degree latitude coordinates, not a mix. In the future, OTS tracks may use a combination of whole and half-degree latitude waypoints to optimize the route for prevailing winds with even more flexibility.

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[1] There are some waypoints with half-degree longitude coordinates at the boundary between different Flight Information Regions (FIRs).

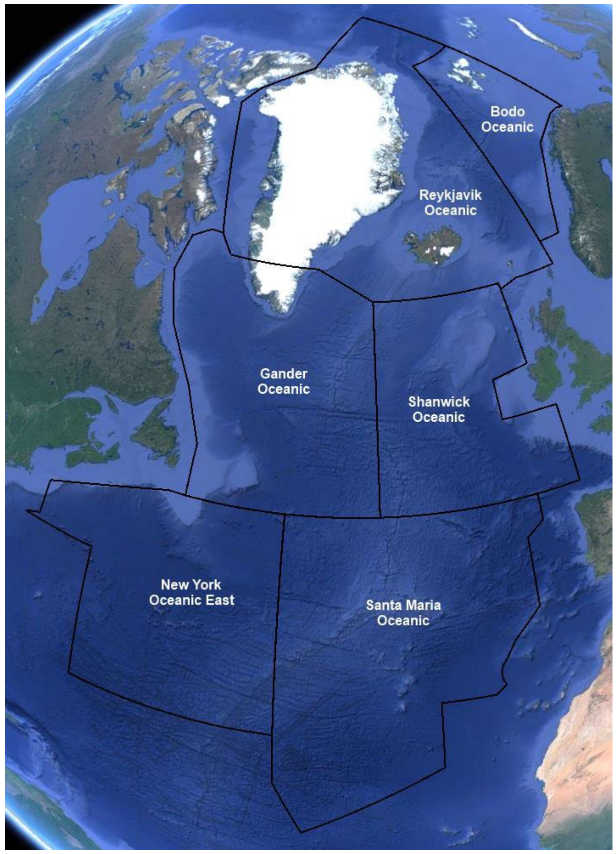

Figure 1. NAT region and geographic areas (ICAO NAT Doc 007, 2020).

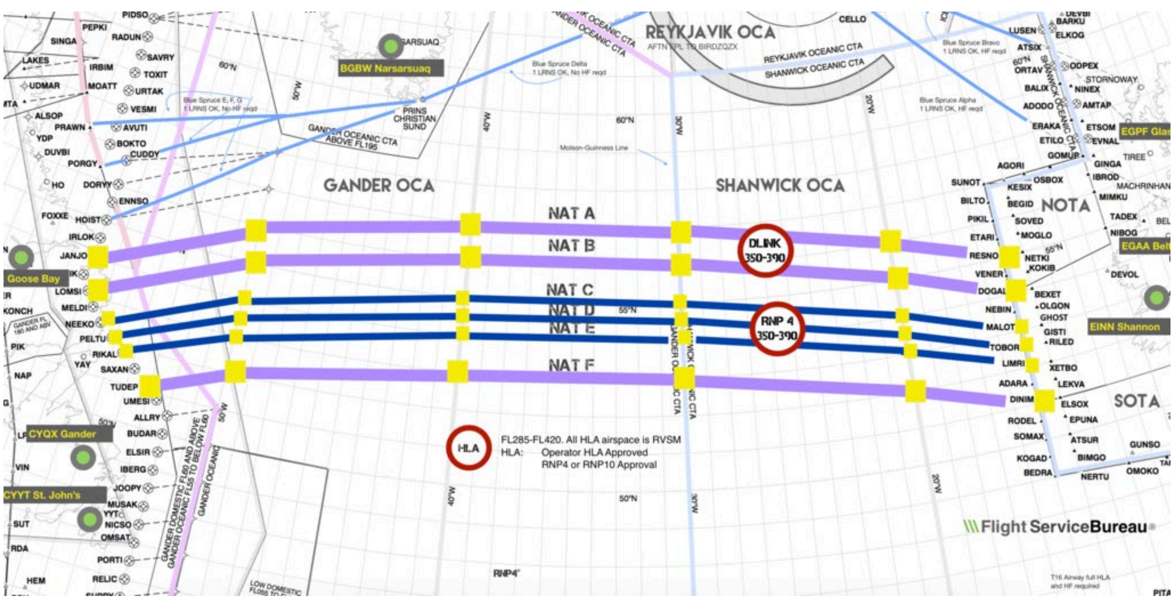

Figure 2. NAT Organized Track System (OTS) tracks for 24 February 2017, from Wikipedia ([image]() by Coisabh, CC BY-SA 4.0)

The Federal Aviation Administration (FAA) Next Generation Air Transportation System (NextGen) program is concerned about the potential for error associated with use of unnamed half-degree waypoints by flightcrews because the use of such waypoints may increase with the implementation of NextGen initiatives such as Trajectory-Based Operations (TBO). It is possible for flightcrews to confuse unnamed half-degree waypoints with unnamed whole-degree waypoints due to non-standard and abbreviated naming conventions on flight deck systems (FAA SAFO 18007, 2018). Such confusion could lead to a lateral deviation that is 10 nautical miles (NM) or greater, which ICAO defines as a Gross Navigation Error (GNE) for the NAT Region.

GNEs represent relatively “large” route deviations, but the NAT CMA also monitors other types of lateral deviations. One is an “Intervention” by Air Traffic Control (ATC), which happens when ATC intervenes in a deviation that would have progressed beyond 10 NM without action. Another type is the “Lateral less than 10 NM” deviation, which would not have progressed beyond 10 NM even without action, due to the difference between the clearance and the incorrectly programmed route. The last type of lateral deviation event is a “Prevention,” where the error was latent in the programmed route, but was caught before the flight actually went off the cleared route.

2 Scope and Purpose

The primary goal of this research was to identify flight deck human factors issues related to lateral deviations that are associated with half-degree waypoints and their waypoint display labels in the NAT. The FAA is interested in determining the magnitude of the problem and identifying mitigation strategies for reducing or eliminating lateral deviations that may be enabled by the flight deck waypoint labels. Our goal is to develop recommendations that could further mitigate the potential for such lateral deviations.

The first step in this research was to analyze the lateral deviations that have been recorded since the introduction of the half-degree waypoint routes on the OTS. To put these events in the proper perspective, we broadened the scope to examine all reported lateral deviations in the NAT that were unintentionally caused by the flightcrew, regardless of whether the aircraft was operating on or off the tracks, and regardless of whether the routes used partial- or whole-degree waypoints. We excluded *intentional* flightcrew deviations such as those for weather, turbulence, or emergencies, and deviations that were due entirely to ATC issues. We also excluded events where contingency procedures (e.g., for weather deviations) were applied incorrectly; this determination was made by subject matter experts who participated in a group review of the deviations (see Section 5.2).

This report has four main sections:

- Background on NAT operations (Section 3)
- Review of related human factors literature (Section 4)
- Analysis of adverse lateral events in the NAT HLA (Section 5)
- Review of flight deck procedures related to NAT flight operations (Section 6)

In Section 7, we summarize our findings from the literature review, analysis of lateral deviations, and our review of flight deck procedures. In Section 8, we discuss the key findings. We consider the implications of this research for the analysis of lateral deviations, for the mitigation of lateral deviations, implications for TBO, and suggestions for related research.

3 Background

NAT operations are described in detail in NAT Doc 007 (2020). This is a lengthy and comprehensive guidance document. This document is not regulatory, but does use the word "requirement" to denote the strength of the recommendation. We will only discuss some highlights here, focusing on issues of relevance to lateral deviations. We introduced the structure of the NAT airspace earlier (Section 1), explaining its geographic region, OTS routes, half-degree waypoint coordinates, and the PBCS trial in the OTS. The NAT Region is evolving and our focus is on the procedures used during 2017 through early 2019, rather than on changes that began after March 2019, because our data is from the earlier time frame.

Section 3.1 below covers flight operations in the NAT HLA, discussing the equipment requirements for communication and position reporting, the route structure, and procedural control. Performance-based navigation is the norm in oceanic flights. Special flightcrew training is also required. Section 3.2 considers pilot tasks in NAT operations. Section 3.3 compares NAT operations with domestic operations in the United States (US). Section 3.4 describes the variability of waypoint names that flightcrews see. Finally, Section 3.5 considers potential flightcrew errors related to the waypoint names.

3.1 NAT Operations

Here we describe NAT requirements for equipment (Section 3.1.1), the route structure (Section 3.1.2), and the air traffic technique of procedural control (Section 3.1.3).

3.1.1 Equipment

Prior to January 2020, Data Link (DL) was required to fly anywhere in the NAT between FL350 and FL390 inclusive.[2] This region is referred to as the Data Link Mandate (DLM) airspace (NAT Doc 007, 2020). Within the DLM airspace, aircraft must be equipped with Controller-Pilot Data Link Communication (CPDLC) for communications (ICAO Doc 10037, 2013) and with Automatic Dependent Surveillance-Contract (ADS-C) for position reports. The OTS resides inside the DLM airspace, so these requirements apply to the track routes. PBCS trials in the OTS, which began in March 2018, also require CPDLC and ADS-C.[3]

CPDLC allows flightcrews to receive route clearances electronically from the ANSP in a format that pilots can load into some aircraft Flight Management Systems (FMSs) (ICAO NAT Doc 007, 2020; ICAO GOLD 10037, 2013).[4] ADS-C electronically sends out aircraft position at contracted locations (e.g., as the aircraft crosses a waypoint) and time intervals (i.e., periodic reports), and in response to events such as a request from ATC. ADS-C messages are updated less frequently than ground-based radar position, introducing some uncertainty in the aircraft's location between position reports.

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[2] Since January 2020, this airspace has expanded to FL290 to FL410.

[3] Specific operator approval is also required for the PBCS trials (ICAO NAT Ops Bulletin 2018_004, 2019a).

[4] On many aircraft, dispatch can use ACARS to load flight plans into the FMS on the ground in US domestic operations. However, the ACARS oceanic application cannot load oceanic clearances from ATC into the FMS. Only CPDLC is able to do that.

Both ADS-C and CPDLC are helpful in identifying lateral deviations. ADS-C generates a conformance alert in ground systems because it automatically sends positions reports including the NEXT and NEXT + 1 waypoints in the FMS route.

3.1.2 Routes

About 50% of flights in the NAT operate on the OTS routes (NAT Doc 007, 2020). These routes are named with a single letter (e.g., Track E) and they have a code number for their effective date/time (the Track Message Identification, or TMI). OTS tracks typically have six waypoints (a named entry point, four unnamed waypoints, and a named exit waypoint).

Flights outside of the OTS operate on more flexible “Random” routes, which are composed of individual named or unnamed waypoints (rather than pre-defined tracks). 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). They may follow the OTS tracks for a part of the route, or they could be composed entirely of unique segments. Random routes can have fewer than six waypoints, or as many as eight or ten waypoints. Some operators develop their own “user-preferred” Random routes and file flight plans for them regularly. Random routes can be composed of either whole or half-degree waypoints, or a combination. Most half-degree waypoints in the OTS use half-degrees of latitude, but Random routes may also use half-degree *longitude* waypoints, though their use is relatively uncommon. Random routes may be used outside the DLM airspace. If so, these flights might not have the communication and surveillance equipment mandated for operations in the DLM airspace.

3.1.3 Procedural Control

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 yet available for NAT operations, ANSPs use procedural control to separate aircraft 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 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.

Over land, there are direct voice communications between the active controller and flightcrew, but oceanic communications today are indirect. In oceanic operations, communications about route clearances between ATC and the flight deck can occur via:

(1) Voice, through a third party (the aeronautical radio station) using a High Frequency (HF) or VHF link,
(2) Aircraft Communications Addressing and Reporting System (ACARS) data link,
(3) CPDLC, or
(4) DCPC via VHF voice radio with a land-based ATC unit on the boundary of the oceanic airspace (which coordinates with the oceanic ATC facility).

If they do not have ADS-C (and are outside the DLM airspace), pilots issue voice position reports via the aeronautical radio station using an HF/VHF link as they cross designated points in the oceanic airspace. In some regions, position reports can also be sent via CPDLC if available.

The NAT is evolving towards PBCS standards (ICAO Doc 6869, 2017b). Space Based (SB) ADS-B is also under development. As of January 2020, all NAT flights require ADS-B Out functionality to support SB ADS-B. The trial of SB ADS-B will last through November 2020. SB ADS-B will enable a breakthrough in the overall concept of NAT operations by providing a radar-like surveillance where such surveillance was not feasible in the past (ICAO NAT ASR, 2019b). Procedural control may not be necessary once SB ADS-B is fully in operation along with SatVoice, which supports direct communications between pilots and controllers. With SB ADS-B and SatVoice, NAT routes may become even more flexible.

3.2 Flightcrew Tasks during NAT Operations

From a flightcrew perspective, procedural control in oceanic airspace is quite different from operations over land in surveilled airspace with DCPC via VHF voice. Crews need to be aware of when they enter and 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 reprogram their FMS if there are revisions to their original (filed) flight plan route. [5]

As mentioned earlier, pilots also use different methods of communicating with ATC in procedural (oceanic) airspace than in surveilled airspace, and communication takes more pre-planning. As a result, pilots 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.

Below we first review the training guidance available to flightcrews for NAT operations (Section 3.2.1). Then we explain recommended navigation checks that help ensure the flight stays on its intended route in oceanic airspace (Section 3.2.2). Next we consider best-practices for reviewing route clearances to avoid lateral deviations (Section 3.2.3). Finally, we review known sources of lateral deviations (Section 3.2.4).

3.2.1 Training

Guidance on crew training requirements for NAT operations is in ICAO NAT Doc 007 (2020). This ICAO document provides guidance for different countries, but local authorities must review operator procedures and provide specific authorization for the different operations (e.g., PBCS). There is some variability in how different operators implement ICAO guidance in terms of formal training and standard operating procedures (SOPs). We review some flight deck procedures for different operators in Section 6 to assess this variation. Some important sections describing flightcrew tasks in NAT Doc 007 (2020) are Chapter 6 on communication and position reporting, Chapter 8 on NAT HLA flight operations and procedures, Chapter 13 on special procedures for in-flight contingencies, Chapter 14 on guarding against common errors, and Chapter 15 on the prevention of lateral deviations.

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[5] Flights whose departure points are less than 30 minutes from Shanwick receive their oceanic clearance on the ground. Similarly, when leaving the New York Oceanic Control Center, the departure clearance issued on the ground is sufficient for entry into oceanic airspace.

The FAA provides guidance on oceanic operations to operators and pilots in different documents and training materials such as Advisory Circular (AC) 91-70B (2016a) and the FAA Flight Standards website NAT guidance document. These materials also include checklists for pilots (including private pilots) and dispatchers. Operators who regularly fly in the NAT likely provide special training for their pilots based upon these and other resources.

While all pilots who fly oceanic operations receive special training to meet the different requirements, pilots who fly oceanic operations regularly may become more familiar with the requirements than pilots who fly these operations irregularly. Practice and familiarity can be especially important since oceanic operations often happen overnight, when circadian rhythms are at a low and fatigue is a factor. Also, oceanic flight time in the NAT is long (5-6 hours) and often includes long periods with low workload, impacting alertness.

3.2.2 Navigation Checks

Crews track their position as they reach each waypoint in oceanic airspace. The waypoints are spaced roughly an hour apart. Plotting is described in NAT Doc 007 (2020) Section 15.2.4(d). They plot positions when they reach the waypoint and then again 10 minutes later to be sure they are headed in the correct direction for the next waypoint. FAA AC 91-170B (2016a) also explains plotting options. One option is to use the electronic navigation display to confirm that ownship is on the active route. The other option is to use a paper plotting chart. If the pilot uses software on an Electronic Flight Bag (EFB) to plot progress, he/she must have loaded the cleared route loaded into the EFB manually.[6]

NAT Doc 007 Chapter 15 (2020), recommends the following procedure at every waypoint:

> Approaching an oceanic waypoint, one flight crewmember should verify the *full latitude and longitude coordinates* of that waypoint in the FMC *[FMS]*, the NEXT and NEXT +1 waypoints, while the other flight crew member crosschecks the latitude and longitude coordinates against the master flight plan/oceanic clearance. [Section 15.2.2(c), italics added]

According to this procedure, pilots will check each waypoint's coordinates multiple times, in addition to other checks conducted when receiving or amending a clearance.

So the key mitigation for potential confusion around half-degree waypoint labels is for pilots to call up (i.e., expand) the waypoint's full coordinates when reviewing the routes programmed in the FMS. The same procedure is also described in FAA SAFO 18007 (2018), the ICAO NAT Operations Checklist (ICAO NAT Ops Bulletin 2017_005, 2017b), and an ICAO NAT Bulletin on Waypoint Insertion/Verification Special Emphasis Items (NAT Ops Bulletin 2018_003, 2019c). The NAT Operations Checklist (ICAO NAT Ops Bulletin 2017_005, 2017b) is a resource for operators, who use the information to develop customized checklists. The oceanic checklist items may be merged into other normal checklists as appropriate.

[6] We are aware of only one operator who uses an EFB to plot positions (see Section 6).

3.2.3 Reviewing Routes

Chapter 14 of NAT Doc 007 (2020) considers how to guard against common errors. Section 14.4 discusses lessons learned, especially in regards to review and entry of routes into the FMS. For example one lesson states:

> **Complete navigation cross checks with more than one flight crew member.** There are some tasks on the flight deck which can safely be delegated to one member of the flight crew, but navigation using automated systems is emphatically not one of them. All such cross-checks should be performed *independently* by at least two flight crew members. [Italics added]

This guidance is reinforced in Section 8.3.12 (NAT Doc 007. 2020), which 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 again, for cross-checking. Section 8.3.15 goes further and recommends that the flightcrew should "silently and independently" load and cross-check waypoints. To improve the verification of revised route clearances, NAT Doc 007 (2020) 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 (Section 8.4.7). These independent checks are intended to reduce the risk of confirmation bias (i.e., "seeing what is expected to be seen") rather than what is actually displayed.

3.2.4 Sources of Lateral Deviations

Considering the flight deck tasks and context, it becomes clear that waypoint naming issues are not the only possible reason for lateral deviations. NAT Doc 007 (2020) describes four common causes of lateral navigation errors (Section 14.3.1), in approximate order of frequency. The first is related to clearance revisions that are not appropriately entered by the crew into the FMS, master flight plan, and/or the plotting chart. The second is when the flightcrew enters a waypoint latitude incorrectly. After entering a series of waypoints with the same latitude, if a forward waypoint latitude differs by a single-digit, crews sometimes mistakenly reuse the latitude from the earlier waypoints. The third case is when the crew inadvertently leaves the aircraft autopilot in heading mode (or other unengaged state) from the FMS route. This can happen due to distractions in the flight deck, or perhaps because the crew had been avoiding weather. Finally, there can be communication errors between ATC and the crew that result in different understandings of the clearance. In some cases, flightcrews hear what they were expecting to hear rather than what was said, indicating confirmation bias. NAT Doc 007 (Section 8.4.8, 2020) also mentions another situation associated with lateral deviations: turnover briefings between crewmembers during long flights, such as after a rest break. These briefings can result in miscommunications and omissions due to distraction or typical human failings.

We discovered examples of these and other possibilities in reports of actual events that were submitted to the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) database, described below:

- The crew might have reviewed only part of the revised route clearance and not the entire clearance, leaving part of the route in its original (now out of date) form in the FMS. This might occur because the crew missed the full text of the CPDLC message (which can go across multiple display screens that the crew may skip or skim) or because the crew thought that they handled all the route changes when they did not, or because the crew did not see the difference(s) between the revised route and the original. Examples from ASRS by ascension number (ACN):

  - ACN 1215694 from November 2014. The crew was unable to print the clearance and did not go to next page of the clearance.[7] They missed a significant reroute.
  - ACN 785639 from May 2008. A crew flying the NAT was issued a revised clearance, but the crew assumed the clearance was "as filed." They missed a significant reroute.
  - ACN 131223 from December 1989 over the Pacific. The crew missed one inserted waypoint in the revised clearance, during a busy time. Only one pilot reviewed the revised clearance. The controller did not mention that the clearance was revised.
- The crew might have been busy or distracted with other tasks, or interrupted by other tasks, causing them to make an error, such as forgetting to expand the waypoint coordinates.
  - ACN 509315 from April 2001. The situation included time pressure, distractions, and a crewmember out of the flight deck for a break. The captain incorrectly cleared the route discontinuity by reverting to the original route after receiving a revised clearance (for Track B instead of Track C).
- Crews may be confused about how the FMS or other flight deck systems handle route revisions.
  - ACN 1204454 from September 2014. Crew attempted to enter a 1 mile lateral offset, but the FMS disengaged LNAV. Crew did not understand how or why this happened.

Anecdotally, it is also possible the crew could have misheard the clearance obtained via voice due to a foreign speech accent, the pace of speech, or background noise. It is difficult to gather evidence of this problem given the nature of voice communications, but the potential exists.

NAT Doc 007 recommends that crews expand the waypoint coordinates multiple times to catch potential route errors. However, such cross-checks may be omitted due to task *shedding,* which is when a person foregoes a task due to task prioritization or lack of perceived utility. In other words, crews may choose not to expand waypoint coordinates because (a) the task was lower priority than other necessary tasks, and (b) almost all of the time, waypoints are entered correctly, and expanding them rarely identifies an error.[8] Shedding or forgetting the task may be more likely when reviewing the route pre-flight, when crews are busy with many tasks, and when maintenance or cabin crew might be interacting with the flightcrew, possibly interrupting the route review. Maintaining vigilance when errors are rare is a well-known problem for human operators.

Humans are also susceptible to confirmation bias, so they are likely to miss small differences between the clearance they receive and the clearance they expect or have already reviewed. For example, as mentioned earlier, sometimes pilots reuse the incorrect latitude for a series of waypoints. The pilots may just be following the pattern for the next waypoint, expecting it to be the same latitude as the previous ones.

In some cases, a deviation may result from a *slip*, which is an unintentional error in executing a correctly intended action. The crew could have made a *slip* type of error when entering the waypoint manually

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[7] Note that ICAO Doc 10037 (2013) does not recommend the use of a printer as the primary means to review a clearance.

[8] Crews may not have negative intentions when they shed a task. They might just have run out of time.

into the FMS, such as reversing two digits in the waypoint coordinates (a transposition error) or by mistyping one digit. For example, in ACN 205928 from March 1992, the crew says they made a transposition error by incorrectly entering a longitude during the rush to enter a revised clearance. Another example of a slip would be if a person presses a key twice by accident (e.g., entering 11 instead of 1 as planned). Slips are normal errors that are difficult to detect and cannot be eliminated through training or cross-checks (Reason and Maddox, 1995; Latorella and Prabhu, 2000; Cardosi and Abbott, 2014). In another example, ACN 1007225 from April 2012, the pilot monitoring accidentally engaged heading select on the mode control panel while returning the flight plan clipboard to the glare shield while flying in the NAT. The error went unnoticed for 5 minutes, producing a 15 NM lateral deviation. Slips are not necessarily related to the system design or lack of crew "professionalism;" they are just normal human fallibility.

3.3 Comparison of NAT and US Domestic Operations

Current domestic operations in the US use named waypoints whose labels are consistent across flight deck displays and ATC systems. Domestic waypoints constructed from ground-based navigation aids have pronounceable names using only letters. With satellite navigation and/or inertial navigation, waypoints can be defined solely by their latitude and longitude coordinates. Such waypoints can be defined over a grid, such as the high altitude (above 18000 ft) National Reference System (NRS) grid over the Continental US (CONUS). The NRS waypoint names have both letters and numbers. There is a similar grid of waypoints over the NAT. In order to increase route flexibility, the grid can use less than whole-degree waypoints. In the NAT many waypoints are defined by half-degree coordinates, and these waypoints do not have published names. Instead, their names include both numbers and letters, which incorporate digits from the latitude and longitude coordinates (see Section 3.4).

In comparison to oceanic routes, routes over land have better surveillance because of ground-based radar (with some exceptions for remote airspace over land, or oceanic airspace with nearby ground-based radar). Over land communications between flightcrew and ATC are also generally faster and more direct. Beyond communications and surveillance, however, there are other differences. For example, weather patterns are different over land. Weather patterns over land can change rapidly and they can have higher impact if the weather is near the airport terminal. Diversions for weather over land can be more complicated than just changing the heading or altitude. Also, over land, aircraft may be flying shorter routes and if they are using performance-based navigation terminal procedures, they may have to fly the routes precisely, relying upon automation. Managing these flight paths can be challenging (Chandra and Markunas, 2017).

So, by many comparison points, flying over land can be higher workload for pilots than flying in oceanic airspace. However, one task that is more complicated in oceanic operations is the need to expand waypoint coordinates for unnamed waypoints. Over land, using published, named waypoints, pilots generally do not expand waypoint coordinates. NRS waypoints are also published, and do not need to be expanded.

3.4 Waypoint Label Variability

Flight deck displays vary a lot. There is no exact mapping between the aircraft type/model and the display capabilities in the flight deck. Displays vary in terms of size, resolution, number of characters displayed, display formats, data displayed, etc. Some of this variation is a function not just of the display hardware, but also of the software version installed in the avionics. Even within a given aircraft fleet for a given operator, different aircraft may have different display capabilities or software versions. Consequently, it is not generally possible to know, after the fact, what a crew specifically saw on their displays when a lateral deviation occurred without extremely specific information that is not likely to be available.

As mentioned earlier, waypoint labels used on the flight deck for unnamed waypoints are an area of concern to the FAA because they may be abbreviated and are not standardized, which may make them more error prone. This may be a particular issue with labels for half-degree waypoints. Here we explore the variability of flight deck naming conventions for half-degree and whole degree waypoints.

One complication with waypoint labels is their sheer variety. Variation in flight deck data formats was identified as an issue in a 1996 FAA report on modern flight deck interfaces; the report includes a table on variability of formatting conventions for navigation position data (FAA, 1996, p. 55). Table 1 is an updated version of the table in the 1996 report. It shows the current formats for waypoint data that flightcrews might see (adapted from Section 2.4a of NAT IMG Decision 44/4, 2014). The formats in Table 1 are only used on the flight deck displays and the FMS. In contrast, Air Traffic computer systems use only full latitude and longitude to identify all unnamed waypoints.

The first row in Table 1 uses the format that describes track routes in the OTS. In the example, the half-degree latitude is clearly different from the whole degree latitude (5030 vs. 50). The difference between whole and half-degree latitudes is also clear in rows 3, 7, and 8, which all are all long formats (greater than 7 characters). Problems in the clarity of the label occur when the number of characters is reduced to 7 or even just 5, as in rows 2, 4, 5, and 6.

Row 4 of Table 1 is a flight deck waypoint label with just 7 characters. The label is created from the waypoint coordinates; for a whole-degree waypoint such as N59°/W40°, the label would be N59W040. However, since the label is limited to 7 characters, a half-degree waypoint cannot be distinguished from a whole degree waypoint using the label alone. Some avionics truncate half-degree coordinates (e.g., truncating N59°30’/W40° to N59W040) while others round the coordinate to create a label (e.g., rounding N59°30’/W40° to N60W040). In either the rounding or truncation case, the existence of the half-degree of latitude is concealed in the 7-character display label. The waypoint’s coordinates have to be expanded by the flightcrew to determine if it is a half-degree coordinate. This is referred to as *display ambiguity* because the waypoint identifier conceals the full latitude and longitude coordinates (Cardosi and Abbott, 2014; FAA SAFO 18007, 2018).

Table 1. Current waypoint labels that flightcrews must manage, adapted from NAT IMG Decision 44/4 (2014).

Row	Source	Example Waypoint Label
1	NAT Track Message • Whole-degree latitude • Half-degree latitude	50/50 (meaning 50°/50°W) 5030/40 (meaning 50°30'N/40°W)
2	ICAO Aeronautical Telecommunications Phraseology (Annex 10) and ICAO Flight Plan Short Format (degrees only, 7 characters)	50N050W
3	ICAO Flight Plan Long Format (degrees and minutes, 11 characters)	5000N05000W
4	7-Character FMS/Map Display after entry using full Latitude/Longitude	N50W050* ** Note that this label could represent either a whole degree waypoint or a half-degree waypoint.*
5	ARINC 424 Paragraph 7.2.5 • Whole-degree latitude name in the NAT • Half-degree latitude name in the NAT	5050N (meaning 50°N/50°W) N5050 (meaning 50°30'N/50°W)
6	ICAO NAT Region Bulletin 2018_003 (2019c) recommendation (Hxxyy for half-degree waypoints, and xxyyN for whole degree waypoints)	5050N (meaning 50°N/50°W) H5050 (meaning 50°30'N/50°W)
7	Typical FMS LEGS page expanded coordinates • Whole-degree latitude • Half-degree latitude	N5000.0 W05000.0 N5030.0 W05000.0
8	RTCA DO-258A Future Air Navigation System (FANS) Interoperability Specification (RTCA, 2005)	500000N0500000W

Row 5 of Table 1 illustrates the naming convention that was developed to standardize flight deck waypoint labels (ARINC 424, Paragraph 7.2.5). The convention was designed to indicate whether the waypoint has a half-degree or whole degree latitude. When used as a suffix, the letter N denotes a whole degree waypoint (e.g., 5940N is N59°/W40°). When used as a prefix, the letter N denotes a half-degree latitude waypoint (e.g., N5940 is N59°30'/W40°). However, this convention is prone to prefix/suffix confusion, where pilots do not correctly interpret the position of the N. This type of error is difficult to catch and not likely to be eliminated through training (Cardosi and Abbott, 2014). And, in fact, there was a sudden increase in lateral deviations just after the introduction of this naming convention (NAT IMG Decision 44/4, 2014). A panel was formed to understand the root cause of these lateral deviations. The panel's final proposal for the NAT Region was to revise the waypoint naming convention slightly. In the modified convention (row 6 in Table 1), the prefix letter for the waypoints in the NAT changed from N to H (so that H6220 represents a waypoint at 62° and 30' latitude North and 20° West). Using H as a prefix and N as a suffix was proposed as a clearer way to differentiate between half-degree latitude and whole degree latitude waypoints. However, since the panel's recommendation is specific to the NAT Region and is not an ARINC convention, the waypoints with these names must be requested by the operator to be entered as custom waypoints in the FMS database.

Unfortunately, the ARINC 424 Paragraph 7.2.5 format is even more complicated than shown in Row 5 of Table 1; the naming convention varies based on region of the world. West of 100° longitude (which cuts through the middle of the US), the N is the middle of the label for whole degree latitudes (e.g., 61N00 means 61° North and 100° West). But, for half-degree latitudes West of 100° longitude, the N is one position to the left of center (e.g., 6N100 means 61° 30' North and 100° West). So there are actually four possible positions for the N in the northern hemisphere. And, the whole ARINC convention uses S instead of N in the southern hemisphere, again with four different possible positions for the letter S. This again, is likely to cause confusion and errors that are not eliminated with training and cross-checks.

Finally, some avionics do not use the ARINC 424 Paragraph 7.2.5 waypoint naming convention. For example, some avionics generate a generic 5 letter and number waypoint name, such as WPT01, in volatile memory; these are user-defined waypoints that are cleared when the system is powered down. These names do not provide any indication of whether the waypoint has whole or half-degree coordinates, nor do they provide any clue as to the geographic location of the waypoint.

3.5 Potential Flightcrew Errors Related to Waypoint Labels

Unclear waypoint labels can make it difficult for the crew to distinguish the intended waypoint from an unintended waypoint during route review. Essentially, the ambiguity could degrade the crew's ability to detect errors in the entry of waypoint coordinates. In such cases, it is critical that crews expand and check the waypoint coordinates and do not rely upon the waypoint label alone during route verification.

However, ambiguous waypoint labels are only a problem if the crew uses them *without* expanding the waypoints. More specifically, the crew might (1) use the flight deck display labels to confirm the route and then (2) *not* expand and check the full waypoint coordinates. Remember though, that waypoint label ambiguity is not the only possible cause of lateral deviations; errors may be introduced in many other ways as mentioned in Section 3.2.4 (e.g., missed part of the revised clearance), and the error might have happened without the crew even noticing the waypoint label, so the label ambiguity would not be a factor.

We describe some mechanisms by which waypoint labels might produce errors below. These errors were gathered from a preliminary review of lateral deviations in the NAT. However, this is not an exhaustive list of possible errors. Our full analysis of adverse events is in Section 5. In the full analysis, we organize and classify these errors based on the following categorization:

1. **Unknown Coordinates of User-Defined Waypoints.** Pilots may not remember what the defining coordinates are for user-defined waypoints. This could result in using that waypoint incorrectly if the coordinates are not expanded during route review. (One lateral deviation in 2017 was traced to a system generated 7-character waypoint label that was initially defined with a half-degree latitude, but the clearance was revised to whole degree waypoints, and flightcrew did not realize the waypoint was still defined with the initial half-degree coordinate.)
2. **ARINC 424 Paragraph 7.2.5 Prefix-Suffix Confusion.** The ARINC 424 Paragraph 7.2.5 convention that uses a prefix versus suffix letter code to distinguish half-degree waypoints from whole degree waypoints is non-intuitive and may be easy to misinterpret. Thus, pilots sometimes reverse meaning of the letter code and believe that a half-degree waypoint is a whole degree waypoint and vice versa. This confusion has been observed in lateral deviations since 2014 (Cardosi and Abbott, 2014; NAT IMG Decision 44/4, 2014). Poor design of the naming

convention can lead the pilot to misinterpreting the route. And, in fact, the world-wide ARINC 424 convention for half-degree waypoint names is not just about the prefix-suffix, but about the position of the N relative to the numbers, which is even more complicated for pilots to remember (see Section 3.4).

3. **Translation across Different Systems and Users.** A translation error can occur when one way of describing a waypoint (an "expression," such as that used by Dispatch) is incorrectly *translated* into another expression (e.g., the waypoint coordinates in the FMS). The inconsistencies in naming conventions between systems and humans (flightcrews, dispatch, and ANSP) could lead to translation errors such that the cleared route (or its revision) is not accurately loaded into the FMS. This may be a problem in particular when the route is entered manually by the flightcrew. This type of error was documented in a case from 2017, where the dispatcher misinterpreted the names of half-degree waypoints and filed them with ATC as whole degree waypoints.
4. **Display Label Ambiguity due to Truncating/Rounding.** As mentioned above, when the display label is either rounded or truncated to 7 characters, the existence of the half-degree of latitude is concealed in the displayed label. So, if the pilot relies upon the label alone, he/she may not be aware whether the waypoint is at a half-degree coordinate, which could result in degraded error detection. There are multiple reasons why a pilot might have failed to expand the waypoint coordinates, mentioned above (e.g., forgetting, distraction, confirmation bias, or intentional task prioritization).
5. **Double Longitude Waypoint Insertion Error.** The error occurs when pilots manually enter a partial-degree waypoint when given a whole degree waypoint. For example, the pilot might enter 62N020W (which is 6220N in the ARINC 4.2.5 Paragraph 7.2.5 convention) incorrectly at a latitude of 62° and 20'. Or the pilot might enter 63N30W incorrectly as 6330N030W, which has a latitude coordinate at 63° and 30' (which happens to be a half-degree of latitude). The error is that the pilot enters the longitude value twice, once as minutes added to the latitude and again as the longitude. This error may occur either because the pilot misread the coordinate or because the pilot manually entered the data incorrectly (a slip). Either situation would lead to the same error. This type of error has been observed and named a "double longitude waypoint insertion error" (NAT IMG Decision 44/4, 2014).

4 Related Human Factors Literature

Here we review the literature associated with human error on the flight deck that may be related to the lateral route deviations in the NAT HLA. We reviewed both academic and applied literature, focusing on papers that apply to aviation and papers that contain literature reviews on human error.

We first review how to classify human errors, in Section 4.1. This background is relevant for the data analyses presented in Section 5. Next, in Section 4.2, we review literature on flight deck data entry errors, their prevention, detection, and mitigation. We would like to understand, for example, what is known about how pilots enter and verify route data in the FMS. We also want to understand what factors could contribute to a failure by pilots to detect route errors.

Finally, because of the FAA's interest in waypoint names on the flight deck, we review a series of studies performed by NASA on the subject of naming waypoints for the NRS. The NRS has many similarities to the system of undesignated waypoints used in the NAT. This material is presented in Section 4.3.

4.1 Error Classification

Latorella and Prabhu (2000) describe three types of classification schemes for human error. The first is a "behavioral" classification. Reason and Maddox (1995) describe this method as "phenomenological." This method looks at the outcome of the error and describes the phenomena that occurred. This type of scheme is objective and descriptive. For example, Berman, Dismukes, and Jobe (2012) use a behavioral scheme to classify errors related to performance data in air carrier operations. They talk about errors and "outcomes" such as tail strikes and high speed rejected takeoffs. Chandra and Kendra (2010) use a behavioral classification scheme to examine errors related to the use of EFBs. Example errors are altitude deviations, deviations from company policy, and runway incursions.

Latorella and Prabhu (2000) identify a second type of error classification scheme as "contextual". These schemes correlate errors with characteristics of the environment and task. For example, errors related to aviation maintenance could be classified by their source, such as operators, equipment, documentation, or task. In the fight deck context, the source of the error might be the flightcrew, the systems interface, documentation, or procedure (which could be incorrect, absent, incomplete, etc.). Such schemes begin to address causality, but are in fact only correlational.

Reason and Maddox (1995) describe another classification scheme that is based on underlying cognitive mechanisms. Latorella and Prabhu (2000) call this a "conceptual" scheme. Conceptual classification schemes assume an underlying task process, typically based on an information processing model. Reason and Maddox (1995) describe the general human performance model consisting of three stages:

- Sensing and perception
- Processing and decision making
- Taking action

In this scheme, the origin of the error is traced back to one of these stages. We and the NAT Scrutiny Group (SG) (Section 5.3) both took this approach.

Finally, Reason and Maddox (1995) describe a higher-level error taxonomy that classifies errors according to human biases or tendencies. Confirmation bias, for example, is when people see what they are expecting to see and fit reality to their expectations. Confirmation bias has been observed in many domains, including aviation. Another well-known bias is the "availability heuristic," a mental shortcut that relies on examples that come to mind quickly. For example, people may expect a type of event to be more common if they have experienced it recently, regardless of its actual frequency of occurrence.

4.2 FMS Navigation Data Entry Errors: Prevention, Detection, and Mitigation

Ideally, errors would be prevented before they occur. However, data entry errors in programming the FMS are not uncommon (PARC/CAST Flight Deck Automation Working Group, 2013). If error prevention fails, then error detection is the next step that needs to occur. Unfortunately, it is not uncommon for flight deck errors to remain undetected in line operations (Thomas, Petrilli and Dawson, 2004). Once an error is detected, then its effects should be mitigated. Here we explore some case studies and industry guidance for flightcrews on error prevention and mitigation.

An important concept in this area is called "threat and error management" (TEM),[9] which is a model for how pilots anticipate and avoid undesired aircraft states, and thus unsafe outcomes. *Threats* are events or errors that occur beyond the influence of the flightcrew. They can be anticipated, unexpected, or latent. *Errors* are actions or inactions by the flightcrew that result in deviations from flightcrew intentions or expectations. Errors that are managed well are detected quickly and resolved without consequential operational impacts. Flightcrews should employ *countermeasure* actions, using available *resources* (e.g., training, checklists, and aircraft systems) to manage threats, errors, and undesired aircraft states.

4.2.1 Latitude-Entry Case Study

An International Air Transport Association (IATA) report from 2011 has case studies on data entry errors for use in pilot training. One of the cases was a lateral deviation in the NAT that occurred due to a combination of the circumstances mentioned in Section 3.2.4. This was a 2006 event which resulted in a 23 NM deviation, which would be a GNE by today's definition. At the time, a GNE was defined as a 25 NM deviation, so the case was labeled a "potential GNE."

The aircraft was cleared on a Random route from the Middle East to the US. The crew observed an odd dogleg in the route over the NAT while cross-checking waypoints, but the route matched the filed flight plan. Several hours into the flight, with the augmenting flightcrew in place by then, they received a revised clearance (via the ACARS printer), which was marked as an ATC route amendment. However, the pilots did not see any difference between the new clearance and the flight plan. They missed a one-degree change to the latitude at one waypoint, which corrected the dog-leg from the original route. The flight-planned coordinate was at 55° latitude, and this had been revised to 56° latitude. The aircraft stayed south of cleared route by 23 NM.

The IATA report (2011) identified the following threats for this case:

- *Confirmation Bias.* The crew saw the route they were expecting to see and adapted reality to their expectations.
- *Manual cross-check of the clearance*. It is easy for humans to overlook a single digit change.

The same report identifies the following errors:

- Crew failure to observe the message ATC/ROUTE AMENDMENT in the clearance.
- Crew overlooked the single digit difference between the clearance and the flight plan.
- Controller did not inform the pilots of their error.

Finally, the report (IATA, 2011) identifies the following TEM strategies that could be employed to manage this type of situation.

- Develop route software to monitor route conformance for use on the flight deck.
- Highlight amendments to the route clearance visually for pilots, to call their attention to the changes.

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[9] See https://www.skybrary.aero/index.php/Threat_and_Error_Management_(TEM)_in_Flight_Operations for more information. Accessed 24 February 2020.

- Flight deck procedures could be to have one pilot read the clearance and the other look at the FMS/display, and to assume that a change has occurred. Also, pilots could verify heading and distances. (Note that this is now standard procedure, but was not at the time of the event in 2006.)
- Keep the augmenting crew involved in flight planning. Because this was a flight from the Middle East, there were several hours between the pre-flight route review and receipt of the oceanic clearance.

The suggestions regarding flight deck procedures and route verification were incorporated in the NAT operations oceanic checklist (ICAO NAT Ops Bulletin 2017_005, 2017b). The mention of software to monitor route conformance is interesting because, today, that is available to ATC, but not to the flightcrew. And in fact, the ADS-C conformance alert is how ATC often becomes aware of a lateral deviation.

Berman, Dismukes, and Jobe (2012) also recommend that better technology and/or better operational procedures can help to improve human error trapping in the flight deck. Their report was on data entry errors in flight performance calculations, but the conclusion applies to all types of data entry into the FMS.

4.2.2 Altitude-Entry Case Study

A report from the Australian Transport Safety Bureau (ATSB) also illustrates FMS data entry issues (ATSB, 2015). In this incident, the crew of a Boeing 777 flight departing from Los Angeles, California, was conducting a visual approach to Runway 34 at Melbourne Airport in Australia. The ATSB found that the crew constructed the approach in the FMS, but inadvertently entered an erroneous altitude that was lower than the required altitude at a waypoint close to the runway threshold. The incorrect location had a similar name (RX34) as the intended location for the constraint (RW34). The aircraft increased its descent rate to meet the crew-entered altitude constraint, descending below the intended flight path. The crew visually recognized the incorrect descent path, disengaged the autopilot, and flew the aircraft level to re-intercept the correct descent path to a safe landing.

The crew did not detect the incorrect altitude entry before conducting the approach, even with multiple opportunities (ATSB, 2015). The crew may have failed to detect the erroneous constraint for a number of reasons including:

- Similar waypoint names (RX34 for the runway extension waypoint vs. RW34 for the runway threshold)
- Spatial proximity; the two waypoints were close to each other.
- The captain elected to complete a visual approach while the flight's first officer was on a rest break. The cruise relief first officer did a gross-error check[10] (i.e., a "ballpark" estimate in the pilot's judgment) while the flight's first officer was away. The gross-error check was done to look for a large discrepancy between the intended flight path and the programmed route, but the discrepancy was too small to be detected this way. Possibly because the route passed the

[10] For more information on gross-error checks, see a guidance document from the United Kingdom Civil Aviation Authority (CAP 1009, 2014).

gross-error check, or because there were other tasks to complete to set up for the visual approach, the returning first officer did not validate the route against the approach chart or Route and Airport Information Manual.

- The crew was fatigued to a level that has been demonstrated to affect performance. Although fatigue was not a confirmed factor, it was consistent with events.

The ATSB concluded that the erroneous data entry was likely to have been a slip, which was an error in the execution of an action, not in the intention. Although the cruise first officer did a cross check, it was done at a high level only, which was insufficient for this situation.

4.2.3 General Threat and Error Management for Data Entry Errors

A 2015 report by IATA considers general FMS data entry error prevention best practices. This report identified the following threats:

- FMS Technology (system design)
- Human performance (normal fallibility)
- Human/machine interface (e.g., controls, displays, input devices such as keyboards, fonts, colors, etc.)
- Organizational factors (e.g., just culture, time pressure, emphasis on fuel savings, rapid culture changes within the organization, service provider for FMS database)

The report presents a long list of potential "traps" and mitigation strategies. Table 2 lists a subset of these from the full report, with examples relevant to route data entry. Finally, the report mentions several general TEM strategies, with themes similar to the mitigations in Table 2. They are:

- SOPs
- Monitoring and cross-checking (although humans are not good at this; training can help)
- Time management
- Workload management, including allocation of functions amongst flightcrew and automated systems
- Gross-errors checks (i.e., compare ballpark estimates to the values in use)
- "Professionalism" (i.e., follow procedures thoroughly, without shortcuts)
- "Mutual mistrust" (i.e., having a "healthy" degree of checking other crew members)
- Education and awareness (training)
- Use of technology designed to prevent errors, such as gross-error checks and monitoring

Table 2. Examples of traps and mitigation strategies related to route data entry, adapted from IATA, 2015.

Example Trap Related to Route Data Entry	**Mitigation**
Use of the FMS	Slow, deliberate use. Understand format conventions and use.
Data transcription. (Potential for misreading, misunderstanding, transposing values, entering incorrect values.)	Verify and cross-check.
Cross-checking. (Laborious checking of routinely accurate data can lead to omissions, oversights and complacency.)	Be diligent. Do silent individual cross checks.
Time pressure. (May lead to short cuts, omissions, errors, and oversights)	Pilot training for handling.
Distraction from others (e.g., visiting the flight deck preflight)	Training and SOPs.
During cruise/climb, route mismatch can cause airspace incursions, etc.	SOPs for checking route amendments and clearances. Check tracks and distances etc.

4.3 Waypoint Labels

The NRS is a grid system of high-altitude waypoints that was created as part of a bigger plan to redesign high-altitude airspace in the CONUS. As of "Phase 2," the grid had 1600 waypoints, with a density of one waypoint every 30' of latitude and 2° of longitude. It was designed to expand significantly, to a density of one waypoint every 10' of latitude and 1° of longitude. This is a greater density and number of waypoints than in the NAT. The NAT waypoints are spaced at 10° longitude (instead of 2°) and usually 1° of latitude, except under PBCS, which goes to 30' of latitude.

Here we first describe the NRS waypoint naming convention (Section 4.3.1). Then we review studies that were done to evaluate and suggest alternatives for the NRS waypoint naming convention (Section 4.3.2). Finally, we gather what we know about criteria for generating waypoint names for the NRS grid. These criteria may apply to generating names for unnamed NAT waypoints as well.

4.3.1 NRS Waypoint Naming Convention

The current nomenclature for NRS waypoints consists of five alphanumeric characters (e.g., KD54U). The first two characters are letters (K, then a facility designator letter, such as I for Indianapolis Air Traffic Control Center or D for Denver), followed by two digits (a "latitude" number, which is not the actual latitude, but a pseudo code), and one letter (a pseudo code for the longitude). The latitude and longitude codes are not unique and repeat as they cut across the US. The nomenclature is designed to encode geographical location data (i.e., the name of the waypoint is related to its position over the CONUS). This is somewhat similar to the display labels of the NAT unnamed waypoints, which also encode latitude and longitude, though not always completely or clearly. NRS waypoint names alternate letters and numbers with the goal to minimize transposition errors.

Several criteria for usability of the NRS waypoint names were initially proposed. Pruchnicki, Christopher, and Burian (2011) paraphrase these criteria from earlier studies:

- Be easy to communicate
- Have low potential for error
- Be consistent with principles that guide names for navigational fixes (five letters, pronounceable)
- Be intuitive as to the general location of the fix (i.e., provide geographic awareness)
- Incur only minimal changes to ground automation (i.e., database changes only)
- Support implementation across US
- Be easier to use than fixes delineated by full latitude and longitude coordinates in order to provide greater route flexibility
- Additionally, names should be no more difficult than current waypoints to enter into FMS computers and flight planning software

NASA conducted two significant studies on the naming of NRS waypoints. These are documented in government reports, one for Phase I (Burian, Pruchnicki, & Christopher, 2010), and another for Phase 2 (Burian, Christopher, Pruchnicki, & Cotton, 2011). These studies were summarized in two conference papers, Pruchniki et al. (2011) for the Phase 1 study and Christopher, Pruchnicki, Burian, & Cotton (2014) for the Phase 2 study.

In the Phase I study (Burian et al., 2010; Pruchniki et al., 2011), researchers describe the naming convention and its use. This study found that the current nomenclature meets many of these initial goals, but not all. Researchers thought some open issues could be addressed as familiarity increased, but this has not worked in practice. Some of the drawbacks of the current naming convention are:

- FMS databases on many aircraft are not able to store the large number of NRS waypoints due to memory limitations, and operators have to trim the set to just the ones they use (Pruchniki et al., 2011). This means that the useable waypoints differ between fleets/types of aircraft, making it difficult to communicate with ATC and dispatchers what routes the FMS is capable of flying.
- Both ATC and pilots reported that the NRS nomenclature was problematic (Pruchniki et al., 2011).
- The nomenclature is complex (with a mix of alpha-numeric characters) and lacks intuitiveness. For example (from Christopher, Pruchnicki, Burian, & Cotton, 2014):
    - NRS names are prone to letter and number confusion, particularly for O (Oakland Center) with the number 0.
    - NRS names are prone to slip errors (e.g., mistyped character or number).
- Pilots lack awareness of where NRS waypoints are, for tactical use.
    - Pilots have difficulty locating NRS waypoints on enroute charts.
    - The pseudo latitude and longitude codes are difficult for pilots to learn and use.
    - The letter denoting the ATC Center facility in the nomenclature is not familiar to pilots. The Center boundaries are also not familiar to pilots. So the letter, and the name of the Center do not help the pilot's geographical awareness. (They do sometimes help ATC or Dispatchers.)
    - The letter K indicates the US Flight Information Region, which is not a useful piece of information because every waypoint in the NRS grid begins with it (Pruchniki et al., 2011).

- NRS waypoints cannot be shown on the fight deck navigation display (ND) unless they are either part of the flight plan (Pruchniki et al., 2011) or if the pilot knows and enters the name. This limits their tactical use for pilots. (Pilots can call up normal area navigation, RNAV, waypoints on the ND, even if they are not along the route of flight, and even without knowing their name in advance.)

In the Phase 2 study (Burian et al., 2011; Christoper et al., 2014), researchers conducted a comparative study of alternative nomenclatures to understand what improvements could be helpful. One suggested improvements was to use a two-letter US state postal code (e.g., MA for Massachusetts) in place of the first two letters of the current name (K and the ATC Center facility identifier). Additionally, the easiest to use alternative nomenclature followed the two letters with three numbers (unrelated to latitude/longitude, but in a logical spatial ordering). Section 5.3.2.1, p. 59 of Burian et al. (2011) also highlights an intuitive result, which is that shorter names take less time to enter manually than longer names. However, Burian et al. (2011) did not find that shorter waypoint names were associated with fewer data entry errors. Data entry error rates were low, regardless of the name being three, four, or five characters.

4.3.2 Waypoint Naming Criteria

Waypoint names for a grid system have to meet several criteria. They should also be tested with different user populations against these criteria. Although the criteria mentioned here were developed for NRS, many of them would apply to the NAT airspace as well. User groups who should be consulted include pilots, flight planners, dispatchers, FMS-database managers, Air Traffic Controllers, Air Traffic Managers and Supervisors.

Burian et al. (2011) provides a list of NRS waypoint nomenclature constraints and goals. Specifically:

- Each waypoint must have a unique (five character) name that imparts geographic awareness. This can be challenging with a dense grid system.
- Users expect consistency of waypoint definitions and meaningful names. The names should not appear to be arbitrary.
- Expandability. There must be an ability to add names in the future (e.g., to increase density of the grid).
- Waypoint names should be resistant to transposition errors. To reduce the risk of transposing numbers, the names should not be composed of only numbers.

The key concepts of uniqueness, geographic awareness, consistency, meaningfulness, and expandability are emphasized above. Pruchnicki et al. (2011) identified additional suggestions for waypoint names:

- A simple and logical naming system is needed to make it easier to use.
- In order to improve options for negotiating strategic re-routes, it is important to be able to display NRS grid structure on ATC radar and flight deck ND. This may not be as much of a consideration in the current NAT airspace, but may be more of an issue when SB ADS-B allows for more flexible routes.
- Limited FMS memory combined with rapid expansion of RNAV instrument flight procedures and waypoints can create pilot workload if they have to know what waypoints are or are not in the

FMS. Also different user groups might not have the waypoints in the same format as others, unless the names are published. It is difficult to communicate about waypoints.

- To connote geographic awareness, it may be best to first break a large airspace region (e.g., the US) into smaller ones (Centers), then numbers within those regions. (An alternative is to just name them within the entire big region, but this is not likely to work as well.) Ideally the smaller regions would be relatively small and similar in size. Area boundaries should be shown on charts, and stay consistent over time. Known regions are easier to learn.
- For NRS grid waypoints, there was a desire to have points named differently than traditionally named (five letter) waypoints. This ensures that there are no duplications of existing names. It also makes it easier to know which points are in the grid. That can be useful if the user needs to be aware that the waypoint is part of a special system.

If ever a naming convention needs to be developed for the unnamed waypoints in the NAT, the criteria developed for NRS waypoints should be reviewed and met. Both positive and negative experiences using NRS waypoints should also be considered, drawing parallels with the NAT airspace as appropriate.

5 Analysis of Lateral Deviations

The NAT HLA has a strong safety record. For 2018, the NAT Annual Safety Report (ASR) key safety performance indicators show that the *number of GNE events* divided by the *number of flight hours flown in the NAT region involving operations with "Data Link not in use"* was 4.79×10^{-6} and with "*Data Link in use,*" the rate was 1.72×10^{-5} (ICAO NAT ASR, 2019b). The same report documents 96 actual lateral deviations in 2018, including 47 GNEs, out of thousands of flights every week of the year. The low rate of lateral deviations in the NAT may be explained in part due to explicit flight deck procedures for reviewing the route programmed into the FMS (see Section 3.2). These cross-checking and verification procedures help pilots trap errors in the routes programmed into the FMS before they are executed. The NAT 2018 ASR (2019b) also notes that there were at 34 ATC Interventions where a controller caught and corrected a lateral deviation before it developed into a GNE and 82 Preventions. Interventions and Preventions are positive indicators that the ATC system recognized an error, warning the controllers in sufficient time to take preemptive action. Most of the errors were recognized through either an ADS-C conformance alert (which checks the FMS coordinates for the NEXT and NEXT + 1 waypoints) or through a CPDLC uplink/downlink message sequence to verify the route in the FMS (UM137/DM40).

The primary goal of this study was to examine the lateral deviations that did occur in the NAT, focusing on GNEs that involved half-degree latitude waypoints, especially those that were on the OTS half-degree latitude tracks. We discuss this analysis in Section 5.1.

We expanded our analysis of lateral deviations in three ways. First, we participated in meetings of the NAT SG (October 2018, March 2019, and October 2019). During these meetings, we learned about the data available to the group and the group's error classification process and scheme. We review the NAT SG data and analyses are in Section 5.2. Their analyses are incorporated into the NAT ASR each year.

We initially used preliminary data from the NAT CMA to analyze 2017 events. Although we had only short descriptions of the 2017 events and not the full data available to the NAT SG, we developed a cognitive task model approach to classify these data. The data and model are presented in Section 5.3. Then we looked at a more recent set of data from all of 2018 and data from January to June 2019. These data last set were analyzed after the NAT SG had completed its review. Therefore, we were better able to exclude cases that were clearly unrelated to half-degree waypoints. We tried out a different error classification scheme on these cases. Rather than attempting to understand the cognitive basis of human error (which was both difficult and often ambiguous), we used a behavioral error classification system based only on the observed differences between the route clearance and the programmed route. This analysis is presented in Section 5.4.

5.1 Impact of Waypoint Display Label

This section focuses on the core question for this research, whether the ambiguous waypoint display labels for half-degree waypoints impact the rate of lateral deviations. We consider both events on and off the OTS. First we present the analysis method in Section 5.1.1, then its results are given in Section 5.1.2.

5.1.1 Analysis

We first reviewed all reported events in a given year to determine whether there was a half-degree waypoint involved. For the 2017 data, we only had access to the brief event summaries and we only reviewed cases where there were half-degree latitude waypoints. For the 2018 and 2019 data, we expanded the analysis to include half-degree longitude waypoints and partial-degree waypoints (e.g., 6215/4149), which are not at the half-degrees. For these years, we also had access to the data after the events were reviewed by the NAT SG, so we reviewed all available materials from the NAT CMA for the GNEs and Interventions. Because of the small number of events that met these criteria, our analysis is qualitative rather than quantitative. Details of each of the relevant events are provided in Appendix A.

We carefully weighed the evidence to decide whether there was indication of a waypoint display label factor. In the cases where we did conclude that there was *some 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 evidence 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 6215N 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 the revised clearance was not entered prior to deviation.
- Crew stated they mis-entered a digit in the waypoint coordinate.

Note that we have no data on how often routes (either filed or cleared) across the NAT involved any half-degree latitude or longitude waypoints. We also do not know whether every event involving a half-degree waypoint was reported by the ANSPs. Therefore we cannot determine the frequency with which lateral deviations occurred using half-degree waypoints versus routes with only whole-degree waypoints.

5.1.2 Results

We identified nine cases in the 2017 data where half-degree latitude waypoints were present in either the cleared route or the flown route (see Table 3). There were six GNEs in 2017 that mentioned a half-degree latitude waypoint, but two of these had insufficient evidence regarding the impact of the waypoint label and two were definitely unrelated to half-degree latitude waypoints. Of the nine cases, six were on the OTS and three were on Random routes. There was just one case of a GNE in 2017 on the OTS where there was some evidence of an issue with the waypoint label; the other GNE with some evidence of an issue with the waypoint label was on a Random route.

We found 11 relevant cases in the 2018 data, consisting of five events with half-degree latitudes, four with half-degree longitude, and two with partial-degree waypoints (see Table 4). All of these cases happened to occur in the first six months of the year. Out of these 11 events, there were four GNEs and seven Interventions. None of these events were on the OTS; they were all on Random routes. Of the four GNEs, two were with partial-degree waypoints, one with a half-degree longitude, and one with a half-degree latitude. Only one of these GNEs, with a partial-degree waypoint, implicated the waypoint label. Two GNEs had insufficient evidence about the impact of the waypoint label, and one was definitely unrelated to waypoint label. Three of the ATC interventions also showed some evidence of an issue with the waypoint label. There was no pattern to these data in terms of the clearance delivery method. Four of the 11 events used Datalink communication, four used VHF/UHF voice communication, two events received clearances from other ground agencies, and one used CPDLC.

Table 5 shows the results from the analysis of January to June 2019 events. There were no GNEs associated with half-degree waypoints in this set. There were two Interventions with some evidence of the waypoint display label factor; one occurred in the OTS and the other on a Random route. The other two Interventions were unrelated to the waypoint display label. Both of these last two events were on Random routes. There were no events in 2019 that involved partial-degree waypoints.

Overall, the impact of the half-degree waypoint labels is limited to a small subset of total recorded GNEs. Across the 2.5 years of data we reviewed, there were only three GNES and five Interventions that showed some evidence of a waypoint display label issue. Given the small number of events, and the highly specific nature of the errors, it likely that the mitigations in place today are generally effective. The remaining cases may occur when pilots do not use the recommended strategies (e.g., expanding all the waypoints every time the route is revised in the FMS) for a variety of reasons. Flightcrew procedures are discussed further in Section 6.

Table 3. Events in 2017 with pilot error involving half-degree latitude waypoints.

	Waypoint Label Impact		
2017 Events	**Some Evidence**	**Insufficient or Inconclusive Evidence**	**Definitely Unrelated**
GNEs	2	2	2
Interventions	0	0	2
Preventions	0	1	0

Table 4. Events in 2018 with pilot error involving any type of non-whole-degree coordinate. All events were on Random routes.

			Waypoint Label Impact	
	Type of Waypoint	**Some Evidence**	**Insufficient or Inconclusive Evidence**	**Definitely Unrelated**
GNEs	Half-degree latitude	0	1	0
	Half-degree longitude	0	0	1
	Partial-degrees	1	1	0
Interventions	Half-degree latitude	3	1	0
	Half-degree longitude	0	1	2
	Partial-degrees	0	0	0

Table 5. Events in 2019 with pilot error involving any type of non-whole-degree coordinate.

			Waypoint Label Impact	
	Type of Waypoint	**Some Evidence**	**Insufficient or Inconclusive Evidence**	**Definitely Unrelated**
GNEs	Half-degree latitude	0	0	0
	Half-degree longitude	0	0	0
Interventions	Half-degree latitude	2	0	1
	Half-degree longitude	0	0	1

5.2 NAT SG Analysis

The NAT SG is tasked by ICAO to examine all reported route deviations in the NAT HLA. The group reviews both vertical and lateral deviations. They also review ATC Interventions and Preventions, as well as use of Strategic Lateral Offset Procedures (SLOP) to mitigate threats from wake turbulence and vertical deviations, and use of contingency procedures for weather-related deviations. The NAT SG members include ANSP and flight deck subject-matter experts.

Below we first describe the process used by the NAT SG (Section 5.2.1). Next we explain some limitations of the data (Section 5.2.2). Finally, we describe the classification scheme used by the NAT CMA. As mentioned earlier, results of these meetings undergo further review and eventually are documented in the NAT annual safety report (e.g., ICAO NAT ASR, 2019b).

5.2.1 Process

Documents related to deviations are submitted by ANSPs to the NAT CMA year-round. The CMA organizes and stores the event records and all supporting materials and carries out an initial analysis of the event. The NAT SG meets twice a year to review all events from the past six months. Each event is presented to the group by the appropriate ANSP with a preliminary assessment of the contributing factors and human error classification (based on the scheme described later, in Section 5.2.3). The group considers the role of ATC and the flightcrew in the event and assigns error categories accordingly.

The supplementary material presented to the group may include detailed position reports, communications between the controller and flightcrew, graphics depicting the route deviation, and responses from the operator to the ANSP describing the crew's recollection of the event. Conclusions from the discussion are recorded by the NAT CMA. Together the NAT CMA and ICAO prepare a summary of the meeting which is later presented to the NAT Safety Oversight Group, which incorporates these data into the NAT annual safety report.

In addition to classifying human error, the NAT SG documents other features of the event, including contributing factors and how the event was detected. In most cases, flightcrews are unaware of the route deviations. Instead, ATC detects errors, perhaps via an automatic route conformance alert based upon ADS-C position report. Methods by which ATC detects lateral deviations are explained in the NAT ASR (2019b).

5.2.2 Limitations of NAT CMA Data

Other than Mandatory Occurrence Reports, ANSPs submit reports to the CMA on a workload-permitting basis. Therefore, the set of adverse events gathered by the CMA may not include all events that occurred. Most ANSPs are able to submit events so the set is fairly comprehensive, but we cannot use it to determine the actual frequencies of event types because some data may be missing. As a general rule, more data are gathered and analyzed for GNEs and Interventions than for Preventions, which have less operational impact.

The ANSP has an option to seek operator feedback using the form in Attachment 1 of ICAO NAT Doc 007 (2020).[11] Unfortunately, these forms are not always returned, and when they are, the response may be insufficient. In the 2017 data we examined, only 1 in 4 of the available operator responses provided useful information that was not already known from the initial report. As of 2018, the NAT SG is tracking the quality of the operator responses. The NAT SG is also now tracking how the deviation was detected and potential mitigations.

Ideally, we would know a lot more about the crew's perspective to determine the error type and its potential mitigation, especially in regards to waypoint labels. For example, a statement from the crew that they checked the waypoint labels, but did not expand the full coordinates would be direct evidence for degraded error-detection due to abbreviated waypoint labels. Or, if the crew stated that there was a mismatch between the waypoint labels on a flight plan from Dispatch and the route clearance, this would be evidence of an error in translating waypoint names across different users.

The lack of information about the flightcrew perspective in lateral deviations is not a new situation. A study of airspace in Sweden (Ternov, Tegenrot and Akselsson, 2004) identified several cases where there was a "mismatch between the flight plan at the Air Traffic Control Center and on the aircraft." The

[11] The CMA may also seek operator feedback for Interventions or Preventions.

authors state that “For these reports, we have only partially identified system weaknesses because we have insufficient data concerning ‘the aircraft side’.”

Efforts to improve data quality about the flightcrew perspective have been attempted, but remain unsuccessful. Even if the NAT CMA were able to get more complete crew feedback through operator investigations, they may not get high quality information because crews may have forgotten the context of the situation. Or, the crew may not even have noticed the error when it occurred and have no insights into what happened and why. The quality of the crew’s recollection of events will be low especially since the event might have happened weeks before the feedback is requested. Unless ATC questions the flightcrew at the time of the event, it may take a few weeks or longer to reach out to crews.

Also, the operator and crews may have concerns about how their input will be used, and about the confidentiality of their data, which adds to the difficulty of getting high quality information about the event. This lack of information about the crew’s actions and rationale makes it difficult, if not impossible, to clearly identify root causes of flightcrew errors.

The only thing we definitely know for all lateral deviations in the dataset is that they went unnoticed by the crew for some time; flightcrew cross-checks and route verification (assuming they were done) did not catch the error that resulted in a GNE, Intervention, or Prevention. The deviations were eventually detected by the ANSP, often through conformance-alert software warnings. Any route corrections made by the flightcrew prior to the recorded data for the event are not known, of course.

5.2.3 Event Classification Scheme

The NAT SG’s approach to classifying the events has evolved over the past two years. Their process is documented in the NAT SG Handbook (ICAO NAT SG19 WP 02). The December 2018 version was used for the classification of events from 2018. An updated version from June 2019 was used for the classification of events from 2019. The NAT SG Handbook also explains not only the review process, but also the categories for two classifications, one for “Contributing Factors” and the other for “Human Error.” A benefit of having the conversation about the human error category is that the group discusses the human factors issues in the event in detail.

The descriptions of the contributing factors for crew-related issues are shown in Table 6, along with expanded explanations (which are not in the handbook). Table 7 lists the different types of human error categories that the NAT SG considered. The tables indicate some changes made in the 2019 version of the handbook. In addition to these changes, the newer version expanded the list of “Other” factors (which were not crew-related). In particular, Dispatch issues are called out separately in the 2019 version and Equipment issues were separated in terms of the type of equipment (Ground-based, Airborne, Data Link, or Other).

Table 6. NAT SG options for contributing factors to crew errors (NAT SG Handbook, 2019).

NAT SG Options for Contributing Factor for Crew Error	Expanded Description
FPL vs CLX	Crew followed the whole flight planned route, or any portion of it, instead of the cleared route.
Climb-Descend without ATC clearance	For vertical errors; crew changed altitude without a clearance
Incorrect Weather Contingency Action	Crew did not correctly follow contingency procedures for weather deviation
Incorrect application of other contingency	Crew did not correctly follow other contingency procedures
Misunderstanding of conditional clearances	Crew misunderstood conditional clearance; this is most often applied to vertical clearances.
Incorrect application of SLOP	Crew incorrectly applied SLOP. SLOP is used to avoid wake turbulence. Pilots can choose to use either a 1 or 2 NM lateral offset to the right of the cleared route.
Truncated Display/ARINC 424 (Paragraph 7.2.5)	This category includes all potential errors related to half-degree *latitude* waypoints. It is assigned whenever such a waypoint was present in either the flight plan or cleared route, regardless of whether it was a factor in the deviation. Partial-degree waypoint issues that are not half-degree waypoints are not identified by this category. Half-degree *longitude* waypoints are not captured consistently in this category.
Waypoint Updating	The waypoint(s) in the FMS programmed route were not updated correctly. This could be because one or more were incorrectly deleted, entered, or modified. This error can apply to any waypoint, named or unnamed.
CPDLC Uplink messages (UM)	The CPDLC message (e.g., UM79 and UM80) is usually specified.
Crew Other	Miscellaneous errors.
Added in 2019: ACARS	Where the message format contributed to the event

Table 7. NAT SG human error types (NAT SG Handbook, 2019).

Error Type	When the operational person…
Action	Made a selection error Made a timing/positioning error Omitted a required action Transmitted, recorded or entered unclear or incorrect information Did not transmit or record required information Did not observe or check the progress or correctness of the flight or systems
Communication	Said or entered an incorrect communication
Workload management	Was unable to or did not adequately prioritize, schedule, initiate, execute, monitor, and terminate multiple concurrent tasks Was unable to or did not properly allocate attention, time, or workload.
Non-conformance	Intentionally deviated from established regulations, procedures, norms or practices. *Note: Intentional acts are not always acts of malicious intent and should not automatically result in disciplinary measures. Individuals may knowingly deviate from norms, in the belief that the violation facilitates mission achievement without creating adverse consequences.*
Perception	Mis-saw or did not see visual information Mis-heard or did not hear auditory information Misunderstood visual information/auditory information, resulting in an erroneous mental representation of the situation
Decision making	Misjudged aircraft/object projection Made an incorrect or insufficient decision or plan Made a late decision or plan Made no decision or plan when required
Memory	Forgot previous action Forgot planned action Had no or inaccurate recall of temporary information Miscalled or had no recall of information in long-term memory
Added in 2019: Unknown	To be used when not enough information is available to determine what human error type(s) contributed to the event.

5.3 Lateral Deviations in 2017

We examined the full set of lateral deviations in 2017 to understand general trends and the variety of events. Details on events with half-degree latitude waypoints were discussed in Section 5.1. Here we first describe the data we had (Section 5.3.1). Next we describe some of the broad trends (Section 5.3.2). Finally, we describe the task-based error classification scheme we developed and how it fared (Section 5.3.3).

5.3.1 Data Pre-processing and Analysis

We obtained the 2017 data from the NAT CMA in the form of brief event descriptions and coded parameters (e.g., type of route, aircraft type, the direction of flight and more) in a spreadsheet. Events from first half of 2017 were obtained from data to support discussions of an ad hoc working group called the NAT Flight Deck Procedures and Ergonomics for Oceanic Clearances and Re-Clearances Project Team (NAT FDPEOCR PT). There were 217 events in the full 2017 data file. Of these, 150 had supplemental data regarding operator responses from the FDPEOCR-PT.

For each event, we:

1) Reviewed and coded it to clarify and classify the error that occurred.

2) Ascribed as many as three possible causes. Multiple causes could be assigned either due to ambiguity or due to the specifics of the event.

3) Determined what types of waypoints were involved, choosing from:

   - Half-degree waypoints
   - Whole-degree waypoints only
   - Named waypoints only
   - Both Named and Unnamed waypoints
   - Other

4) Used the classification of possible causes to exclude events that were clearly unrelated to half-degree waypoints. In particular, we deleted cases with these types of causes:

   - ATC or Dispatch error
   - Intentional deviations by the flightcrew
   - Weather-related flightcrew errors
   - Errors in following Strategic Lateral Offset Procedure (SLOP)
   - Aircraft performance limitations or equipment malfunction/failure

After excluding cases based on criteria above, the set had 169 events including Preventions and Interventions. We did not analyze Preventions and Interventions separately from GNEs.

5.3.2 Findings

Of the 169 events in the set, just 20 cases were for flights operating on the OTS, and the remaining 149 were flights on Random routes. Ten of the cases were for flights operating outside of the HLA, two of which involved half-degree waypoints. We kept these cases in the analysis. We estimated that there were approximately 40 GNEs in the set of 169 events, but we did not confirm whether these were officially classified as GNEs by the NAT SG. The six GNE events that included half-degree waypoints were discussed earlier (Section 5.1).

According to ICAO NAT Doc 007 (2020) (Section 8.1.7), currently about half of NAT flights use the OTS. Given that Random routes had well over double the errors for OTS routes, they may be especially prone to lateral deviations for some reason. Because our event data set may be incomplete, we cannot provide hard data on this discrepancy. However, other data available to the NAT Mathematician's Working Group confirms the basic conclusion (C. Falk, personal communication, March 7, 2019). Some of the potential explanations for this discrepancy are considered in Section 7.2.3.

We also found that crews made route errors with both named waypoints and unnamed waypoints. There were 37 cases where the cleared route differed from the programmed route with incorrect named waypoints. There were even errors when the waypoints had highly dissimilar, standard 5-letter names (which are labeled correctly on flight deck displays). Most of these events did not turn into GNEs.

Three GNEs were recorded with named waypoints, and the other 34 cases were Preventions or Interventions.

5.3.3 Cognitive Task Error Classification Scheme

As part of our analysis, we developed our own cognitive-task error classification scheme. This scheme is customized for flightcrew tasks related to processing a clearance (see Table 8). We felt this task was the most appropriate one to focus on given that the issue of concern is the entry and verification of half-degree waypoints in FMS. The first three steps in Table 8 are related to the *perception* and interpretation of the clearance. The last four steps are related to the *actions* necessary for executing the cleared route.

When we tried to use this classification system however, we found that many of the events were ambiguous, and the error could have originated from more than one of the information processing steps. We were able to classify flightcrew errors in most cases, but 38% of the events did not have sufficient information for us to categorize the error. The data often listed the reason for the error as just "followed flight plan instead of clearance" with no further explanation. That is, the crew did not update the avionics to match the clearance delivered by ATC. This situation rules out some errors in Table 8.

Table 8. Preliminary cognitive model for crew errors related to route entry and review in the FMS.

Steps in Processing Clearance (in order)	Corresponding Potential Crew Error if Step is not Completed Correctly
1. **Crew looks at entire clearance**	Incomplete reading (crew fails to read entire clearance)
2. **Crew reads clearance**	Misperception of clearance
3. **Crew interprets clearance**	Misunderstanding of clearance
4. **Crew plans to enter clearance**	Non-entry of clearance (crew fails to enter clearance)
5. **Crew keys avionics to enter/accept clearance**	Entry slip
6. **Crew cross-checks entry and activates avionics**	Error in avionics use
7. **Crew follows operational procedures**	Operational Procedure error

5.4 Lateral Deviations in 2018

In October of 2018, we participated in the NAT SG meeting. After the events were reviewed, the NAT CMA generated a custom data file for us. Because the data were obtained after the SG review, we had more confidence in their completeness. Also, with exposure to the NAT SG review process, we had a better understanding of the data.

We first describe the data we received (Section 5.4.1). We applied a different, more objective, behavioral error classification scheme to these events. The new scheme directly compares the cleared route with the flight plan route without any inferences or speculation. We describe lateral deviations by the maximum deviation in nautical miles, the number of waypoints that were incorrectly entered in the FMS, and the types of waypoints (named versus unnamed) that were incorrectly modified, inserted, or deleted. In Section 5.4.2 we describe the general data trends. Finally, we describe the results of the behavioral error classification scheme (Section 5.4.3). Details on events with half-degree latitude waypoints were discussed earlier, in Section 5.1.

5.4.1 Data Pre-processing and Analysis

We obtained 74 reports from the NAT CMA based on the following criteria:

- Six months of events from January to June 2018, which were reviewed by the NAT SG in October 2018
- Included lateral events (including events that also had a vertical deviation)
- Included events with flightcrew error and kept events if they had both flightcrew and ATC errors, or if they had a Dispatch component

For each event, the data file contained the:

- Date and CMA reference number of event
- Type of event (GNE, Prevention, or Intervention)
- Aircraft type
- Route type (Random or OTS)
- Clearance delivery method (ACARS, CPDLC, Voice)
- ATC cleared route
- Route flown
- Maximum lateral deviation (in NM)
- NAT SG classifications for “Contributing Factors” and “Human Error”
- Whether the operator was private or commercial
- Whether the operator response was sufficient

The data did not include the original filed flight plan. That information was sometimes available in the detailed files, but not always.

We removed six cases from the 74 in the set from the NAT CMA for a variety of reasons. We were unable to verify the lateral deviation for some events (e.g., because a SLOP error or because of a joint vertical and lateral deviation). In one case there was an unruly passenger, another case had two flight plans (ATC had the new one, but the flightcrew had the old one), and one case was an intentional weather deviation with incorrectly applied contingency procedures. This left us with 68 cases for our analysis. Four of these events had contributing ATC errors as well. Thirty-five of the 68 had sufficient operator responses.

The most common NAT SG contributing factors (see definitions in Table 6) for our data set were:

- 32 flight plan instead of clearance
- 26 waypoint updating
- 6 truncated display of waypoint label
- 5 CPDLC message issues (e.g., UM79, a route clearance uplink with “VIA” phrasing)

In terms of human error classifications, the NAT SG values for crew errors in this data set were:

- 45 Action errors
- 20 Perception errors
- 5 Decision-making errors
- 2 Workload Management errors

The human error classification was related to the contributing factor, but not directly. For example, of the six events with truncated display of a waypoint label, four were classified as Crew Perception errors, but two were Crew Action errors. Most of the waypoint updating errors were classified as Crew Action errors (21 out of the 26), but four were classified as Crew Perception errors and one was a Crew Workload Management error. Twenty of the 32 "flight plan instead of clearance" errors were classified as Crew Action errors, but Crew Perception was also assigned to this contributing factor in ten cases.

5.4.2 Findings

Of the 68 cases we reviewed, only one was on the OTS while the other 67 cases were on Random routes. This replicates the finding from the 2017 data, that is, the vast majority of lateral deviations occur on Random routes, not the OTS. The set included 32 Preventions, 20 Interventions, and 16 GNEs. (The Interventions were not subdivided as to whether they would have been less than 10 NM without ATC action or not.) 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 delivery type of the clearance, but there was no trend in Preventions, Interventions and GNEs as a function of the clearance delivery method.

5.4.3 Behavioral Error Classifications

We counted the number of discrepant waypoints between the cleared route and the FMS programmed route (see Table 9). Forty-eight of the 68 events (70%) involved only one discrepant waypoint. Of the 48 cases with one errant waypoint, 36 involved coordinates for unnamed waypoints and 12 involved discrepant named waypoints. Of the remaining 20 cases, 17 involved two discrepant waypoints, and only three involved 3 or more waypoints. Six events (out of 20 with two or more waypoint errors) involved both named and unnamed waypoints. This pattern of errors indicates that the incorrect waypoints were probably not entered systematically.

Named waypoints had a higher rate of cases with two incorrect waypoints (six cases out of 18) than unnamed waypoints (seven cases out of 44). This may be because named waypoints are paired at oceanic entry and exit points. Of the six errors involving both incorrect coordinate and incorrect named waypoints, four of the six involved two waypoints, and two of the six involved three waypoints.

We also looked at the types of discrepancies between the cleared route and the programmed route as a function of the number of discrepant waypoints. We coded whether a waypoint had been Deleted (in the cleared route), Inserted (in the cleared route), or Modified (in the cleared route), or a Combination of Changes (for cases with two or more discrepant waypoints). These data are shown in Table 10. The most common changes were to modify one or two waypoint (46 of 68 cases).

Table 11 shows how the different types of waypoints related to the type of lateral deviation. Of the 18 cases with named waypoints, ten were Preventions, five were Interventions and three were GNEs. Errors with named waypoints appear to be caught early and result in Interventions or Preventions more than they result in GNEs. This trend was also observed in the 2017 data. Of the 44 cases involving only coordinates, there were 17 preventions, 14 interventions and 13 GNEs. Of the six cases involving errors in both named and coordinate points, there were five Preventions and one Intervention.

Table 9. Number of discrepant waypoints as a function of type of waypoints with discrepancies.

Number of Discrepant Waypoints	Named-Waypoint Discrepancy	Unnamed-Waypoint Discrepancy	Both (if two or more discrepancies)	Total
1	12	36	n/a	48
2	6	7	4	17
3	0	0	2	2
5	0	1	0	1
Total	**18**	**44**	**6**	**68**

Table 10. Types of discrepancies between cleared route and programmed route as a function of the number of discrepant waypoints.

Number of Discrepant Waypoints	Deleted	Inserted	Modified	Combination of Changes	Total
1	5	10	33	n/a	48
2	0	2	13	2	17
3	0	0	2	0	2
5	0	1	0	0	1
Total	**5**	**13**	**48**	**2**	**68**

Table 11. Type of lateral deviation as a function of type of waypoints with discrepancies.

Event type	Named-Waypoint Discrepancy	Unnamed-Waypoint Discrepancy	Both (if two or more discrepancies)	Total
Prevention	10	17	5	32
Intervention	5	14	1	20
GNE	3	13		16
Total	**18**	**44**	**6**	**68**

5.5 Lateral Deviations in 2019

We also examined latera deviations from January through June 2019. We received these data from the NAT CMA as well. The events were selected using the same criteria used for the 2018 events, except that a slightly updated classification system was used (see Section 5.2.3). After excluding any cases that were explained by other factors (e.g., weather deviations, SLOP, or insufficient data about the lateral deviation), there were 57 events in our dataset (which is similar to the number of events we had across the same 6-month period from 2018).

The most common NAT SG contributing factors that were crew-related for the 2019 data (see definitions in Table 6) were:

- 40 flight plan instead of clearance
- 19 ACARS message format
- 12 CPDLC message issues (e.g., UM79, a route clearance uplink with "VIA" phrasing)
- 5 waypoint updating
- 2 truncated display of waypoint label

In terms of human error classifications, the NAT SG values for crew errors in this dataset were:

- 22 Action errors
- 18 Perception errors
- 12 Unknown
- 2 Decision-making errors
- 2 Workload Management errors
- 2 Memory

One notable shift between the 2018 and 2019 data was that the newly added categories (ACARS message format contributing factor and the Unknown human error category) were used relatively frequently.

We also analyzed the 2019 data in the same way we analyzed the 2018 data, using a behavioral error classification. The new dataset largely matched the older set. For example, the majority of events (41 out of 57) had only one incorrect waypoint. Named waypoints were again not free from errors; for cases where one waypoint was incorrect, that waypoint had a name in 14 cases, and was unnamed in 27 cases. Once again, the bulk of lateral deviations occurred on Random routes. In the 2019 data, just six of the 57 deviations were on OTS routes. And again, the most common change to the flight plan was to modify a single waypoint coordinate (27 out of 57 cases). The only minor change we found was that there were five GNEs associated with named waypoints and six with unnamed waypoint coordinates. Named waypoints did not appear to be less prone to GNEs than unnamed waypoints in the 2019 dataset, but this could be a typical level of variation.

6 Flight Deck Procedures for Route Review

Although the NAT Doc 007 (2020) provides extensive recommendations for NAT flight deck procedures for reviewing routes and reducing lateral deviations (see Section 3.2), these procedures do vary across operators. The general process is similar, but it is implemented in different ways. For some operators, pilots expand the coordinates for all unnamed waypoints both pre-flight and again in-flight as they approach and cross over the waypoint. So these procedures have pilots expand and recheck the coordinates of unnamed waypoints multiple times in flight, and again if the route is revised. However, operators who do not use the half-degree latitude tracks may assume they will not get a clearance with half-degree waypoints, and so they may not always expand coordinates. This, unfortunately, may be a mistaken assumption.

The purpose of this part of the study was to understand the variability of flight deck route review procedures. For example, since we knew from our analysis (Section 5) that there were more lateral deviations on Random routes than OTS tracks, we wondered whether there were differences in how Random routes are verified or monitored. We were also curious to understand whether the recommended flight deck procedures and training were effective in reducing GNEs. And, when a lateral deviation did happen, we wondered how pilots responded. We could not answer all of these questions definitely, but we made progress on understanding the issues.

6.1 Method

We spoke with representatives from a variety of operators to gather factual data about their NAT operations. The discussions were conducted in phone or in person. Each conversation took approximately one hour. The discussions occurred between December 2017 and October 2018. Most of these were passenger airlines, but we included one cargo operator and one corporate operator. Of the seven, four were based in the United States and three were based internationally.

The topics discussed are listed below:

1. Characteristics of operation
    - Use of CPDLC, use of half-degree waypoints, EFB, etc.
    - Typical routes
    - Flight planning process
    - Internal error tracking process
2. What procedures do flightcrews follow to verify an oceanic clearance?
    - Training materials
    - Verification steps and pilot roles
    - Use of NAT Operations checklist
    - Use of route printout
3. How do crews monitor their flight path (along the oceanic route)?
    - Use of paper plotting chart
    - Use of flight deck displays
    - Pilot roles
4. Flight Deck Display Capabilities
    - Waypoint labels and ability to display unnamed waypoints
5. Lateral Deviations
    - Experiences, resolutions
6. Opinions
    - How best to address lateral deviations?
    - Waypoint naming conventions?

6.2 Findings

Our detailed findings are presented in the tables in Appendix B. In addition, three operators provided us with sample Operational Flight Plans (OFPs) and trip kits[12] for sample flights. Two operators sent us

[12] A trip kit is a package of information for the pilot about the specific flight. It contains information and files such as the operational flight plan, fuel data, airport and airspace information, weather data and charts, notices to airmen, and NAT track routes.

sample training materials. The tables reflect the conversations and therefore may have more information on one topic, and less or no information on a different topic.

One of our questions was whether Random routes were verified or monitored differently than OTS routes. The response was that the process of expanding waypoints was the same for both types of routes. The only difference was, for OTS routes, pilots had to verify two additional items, the TMI and the track letter code.

One of the differences between operators was how frequently their pilots were instructed to expand the full waypoint coordinates. At a minimum, all pilots were expected to expand the coordinates during the pre-flight route review, and again if they are given a revised clearance in flight. However, some operators asked pilots to expand the coordinates many times, or each pilot expanded the waypoints independently, to ensure redundancy. Consistent with recommendations in NAT Doc 007 (Section 15.2.2(c), 2020), two US passenger airlines asked pilots to expand the waypoints for the next waypoint and the waypoint after that (the NEXT + 1 waypoint) all throughout the flight, meaning that the coordinates were expanded several times.

We also learned about the number of steps it takes for the pilot to expand the waypoint coordinates. For example, although an FMS database may have the Hxxyy label for half-degree waypoints, some operators discourage use of these names because it takes four to six key strokes to expand their waypoint coordinates on the aircraft types they fly. The pilot has to first select the waypoint, then pull it into the Control and Display Unit (CDU) scratchpad, and then pull up the reference navigation data page (see Figure 3). Instead, operators prefer pilots to use the 7-character FMS label because it only takes one key stroke to expand their waypoint coordinates. Also, within a single aircraft, pilots may see multiple naming conventions (as shown in Figure 4).

Figure 3. Waypoint data page showing the ident (H5720) and the full latitude-longitude coordinates.

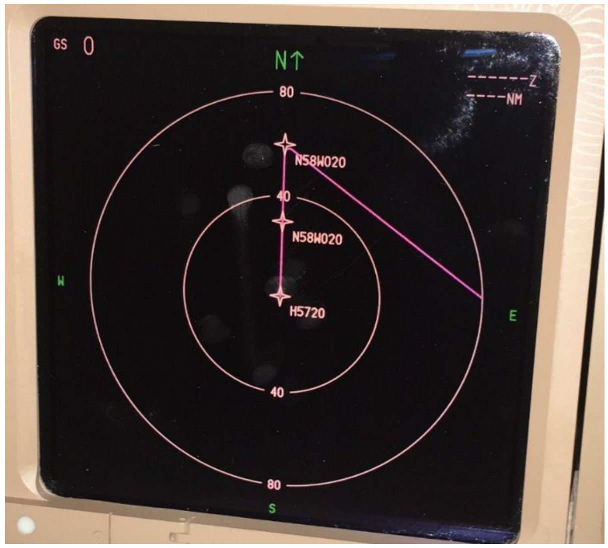

Figure 4. Navigation display on B-777 showing both the 7-character waypoint labels and the H-prefix waypoint label.

Some operators mentioned that they had EFBs that supported their oceanic operations in different ways. One of the support applications was Jeppesen's FliteDeck Pro for iPads, which has oceanic data-driven charts that show ownship position. While not to be used for navigation, this application and depiction could be used as an independent check on the route the aircraft was flying according to the FMS. Also, one of the EFBs had software for plotting position reports in a graphical format. Other operators used paper charts to log position reports. However, we also learned that plotting positions on a chart is not a reliable way of detecting deviations of 10 NM, which are considered to be GNEs. A deviation this size can occur within a few minutes, and the plotting is too infrequent for the pilot to reliably detect such errors.

Finally, although operators are aware that expanding waypoints is a necessary check, and they know that checking distances and course between waypoints is also a key error mitigation strategy, some of them also built in other procedural checks. Some examples of other procedural checks include:

- Review and verification of route on the EFB in the crew briefing room, with fewer distractions and less time pressure than in the route review of the FMS route pre-flight.
- Independent verification of the route and waypoint coordinates by each pilot.
- Checking different aspects of the route at different times. For example, check the waypoint coordinates on the ground, but check the distances and course in flight.

7 Summary of Results

7.1 Literature Review

- <u>There are multiple approaches to classifying human errors associated with lateral deviations.</u> The NAT SG approach to analyzing and classifying lateral deviations is a work in progress. Even with the current limitations, it is important and valuable to discuss the flight deck (and ATC) human factors issues that factored into each event to gain a deeper understanding of when and how an error could be detected or prevented as early as possible.

- There is substantial existing guidance for flightcrews on how to prevent, detect, and mitigate data entry errors on the FMS. In addition, there is guidance for flightcrews specific to operations in the NAT that highlight flight deck procedures, especially those related to checking expanded waypoint coordinates in the FMS. The procedures recommend multiple independent checks of the route data in the FMS. Pilots can use threat and error management concepts to help anticipate and prevent potential errors. However, it is difficult to prevent every error, so error detection and mitigation are important.
- Considerable effort went into ensuring that the naming convention for the US grid of NRS waypoints would work well, but there are still barriers to smooth adoption and use. Some of the barriers are technical, such as limitations to the FMS database size, and some are related to human factors issues, such as the difficulty of associating a waypoint name with a geographical location.
- Developing a naming convention for unnamed waypoints is a challenging problem that requires testing and validation with multiple stakeholders. There are many criteria that need to be considered, and these can be hard to reconcile. For example, names should be both distinctive (i.e., not easily confusable), but also meaningful (not random letter combinations) and pronounceable (with syllables and a mix of consonants and vowels). The naming convention should also be intuitive and logical, while also providing geographical awareness, but the logic must not be overly complicated.

7.2 Data Analysis

7.2.1 General Observations

- Lateral deviations have been occurring in oceanic airspace for years. There are events in the ASRS database dating back to its earliest records from the late 1980s. We could not determine whether the overall rate of lateral deviations has increased or decreased.
- ICAO's methods of recording lateral deviations and calculating risk have evolved. For example, the definition of a GNE changed from a deviation greater than 25 NM to a deviation greater than 10 NM in August 2017.
- Lateral deviations often are the result of a combination of circumstances and actions (or inactions). For example, an initial data entry error (perhaps just a single digit) might go unnoticed even as pilots cross check and verify the route. Time pressure, distractions, and many other operational factors play a role in lateral deviations.
- There are substantial limitations to the available data about lateral deviations. For example:
    - Only reported events are available in the dataset, and other than mandatory reports, not all events are reported. So, the frequency of events cannot be analyzed. A separate NAT working group performs a mathematical analysis of collision risk, looking at the time aircraft spent "unprotected" by an ATC clearance. Our analysis does not look at collision risk.
    - We could only analyze individual events qualitatively.
    - We have little contextual information about the actions and rationale of the flightcrew during a lateral deviation. We only know (1) the outcome of the error (a deviation or potential for deviation), and (2) that the crew failed to detect the route discrepancy.

Although we can make some predictions based on human factors expertise, we cannot know exactly what happened with the available data.

7.2.2 Lateral Deviations Associated with Half-Degree Waypoints and Waypoint Labels

The primary goal of this research was to identify flight deck human factors issues related to lateral deviations that are associated with half-degree waypoints and their display labels in the NAT. Our first task was to assess the magnitude of the problem.

- The number of events involving half-degree waypoints is a small subset of the overall number of reported events with flightcrew issues. Out of the 24 events (from 2017,2018, and the first six months of 2019) where half- or partial-degree waypoints (either in latitude, longitude, or both) were involved, there were just eight that had evidence of issues with the waypoint display label, three GNEs and five Interventions. Many more lateral deviation involve errors in updating the route of flight to match the ATC clearance (NAT ASR 2018, 2019b).
- Given only eight cases with sufficient evidence for evaluation, we could not establish a pattern for human factors issues associated with half-degree waypoints and their labels. One factor might be the fact pilots make mistakes using the ARINC 4.2.4 Paragraph 7.2.5 naming convention; it is easy to misinterpret or not notice the position of the N in the waypoint display label. It is also possible to err by entering the longitude as minutes in the latitude field. In at least two cases, such errors were made by flight planning staff other than the flightcrew, and the flightcrew did not catch the error during route verification.

We cannot determine whether the frequency of adverse events involving half-degree waypoints and display labels has decreased over time with the current data because we do not know either the *exposure rate* (i.e., how often half-degree latitude waypoints are used in either the cleared or flight planned route) or the *total number of lateral deviations that occurred* (because some deviations may not have been reported). Therefore, the zero lateral deviations involving half-degree latitude that we found in latter half of 2018 could either be the result of fewer aircraft flying the half-degree tracks because of the changeover to PBCS, or the result of improved mitigations for half-degree waypoints. It is also possible with such a small number of events overall, the rate of deviations is so low that having zero events in the last six months of 2018 is a normal statistical variation.

7.2.3 Lateral Deviations in General

We also looked at the full set of lateral deviations to understand the general flight deck human factors issues. We gained the following insights about lateral deviations overall in the NAT through our data analyses and through our participation in the NAT SG.

- Random routes in the NAT HLA appear to be more prone to errors than routes in the OTS, but we do not know why, or by how much. This pattern is clear in the dataset. Some possible explanations include:
    - Random routes are more likely to be revised than routes on the track systems so there will be more opportunity to make mistakes.

    - Flight operations outside of the DLM airspace do not require CPDLC. In theory, CPDLC could reduce errors. However, we saw no pattern relating the number of lateral deviations to the clearance delivery method in our 2018 data.
    - Random routes can have more waypoints than track routes, which could also increase the opportunities for error.
- Revised route clearances are a risk factor for route deviations. As discussed in Section 8.4.7 of the NAT Doc 007 (2020), "Experience has clearly shown that when ATC issues an initial oceanic clearance that differs from the flight plan, or subsequently during the flight issues a re-clearance involving re-routing and new waypoints, there is a consequential increase in the risk of errors being made. Indeed, errors associated with re-clearances continue to be the most frequent cause of Gross Navigation Errors in the North Atlantic HLA."
- Errors in flight deck route programming can go unnoticed. It is hard (if not impossible) to know how the error occurred and why it went unnoticed from the event data. If the error were noticed, it would have been corrected and not resulted in a recorded lateral deviation.
- Most lateral deviations are caught by ATC before they become GNEs, either through an ADS-C conformance alert or a CPDLC uplink/downlink route confirmation (NAT ASR 2018, 2019b). SB ADS-B will also improve surveillance capability in the future. Although pilots monitor their flight progress in flight on a regular basis, they are not likely to catch a lateral deviation before it becomes a GNE. GNEs can occur in just a few minutes of flying off the route. Pilots plot their progress at roughly hourly intervals (FAA AC 91-70B, 2016a; NAT Doc 007, 2020), too infrequently to catch a GNE before ATC does.
- Both named and unnamed waypoints are implicated in lateral deviations.
- From the analysis of 2018 and 2019 events, when there were errors in the route programmed in the FMS, often only one waypoint was discrepant. A typical error was that a single waypoint coordinate was modified. These types of errors are relatively easy to make and difficult to catch. This type of error is also mentioned as a common situation in Section 14.3.1 of NAT Doc 007 (2020), which specifically calls out modifications of a single digit to the latitude after a sequence of waypoints with common latitudes.

7.3 Review of Flight Deck Procedures

- Half-degree waypoints are not reviewed differently than whole-degree waypoints. All waypoints are supposed to be reviewed and expanded individually by flightcrew.
- It is important for pilots to remember to expand each waypoint coordinate, regardless of whether they are flying on a Random or OTS route. Half-degree waypoints can be in clearances for Random routes. When they are part of a Random route, there may be a mix of whole-degree waypoints and half-degree waypoints.
- Flightcrew verify the track letter (name) and TMI for OTS routes. Otherwise, they treat Random routes and OTS routes the same in terms of verifying the waypoint coordinates.
- Crews may not expand the waypoint coordinates if they assume they will not be assigned any half-degree waypoints. (This may be the situation for operators that are not participating in the PBCS trial who assume that only aircraft on PBCS routes can be assigned half-degree waypoints.)
- Aside from waypoint labels, there are many other potential reasons why the programmed routes differed from cleared routes (see Sections 3.2 and 8.1). Some of these are documented in the NAT Doc 007 (2020) and in reports from the NASA ASRS database.

8 Discussion

Here we consider the broader implications of this research. First we consider the different ways of analyzing lateral deviations and their strengths and limitations (Section 8.1). Next we consider near-term and longer-term options for mitigating lateral deviations related to half-degree waypoints (Section 8.2). Then we consider implications for TBO (Section 8.3). Finally, we consider suggestions for additional research (Section 8.4).

8.1 Assessment of Analysis Methods

8.1.1 NAT SG Review

The NAT SG will continue to monitor and evaluate lateral deviations for contributing factors and human error. Their analysis covers all reported deviations (vertical and lateral) across the NAT, and includes events that have ATC or Dispatch issues, not just flightcrew issues. Their work does not focus on a particular type of event, as we did. The review process will evolve as needed to adapt to changes in the airspace and operations. As this group continues its work, it will be useful to keep improving the classification process described in the NAT SG Handbook (2019).

The NAT SG gathers as much data as possible about each event, which is critical. They know, for example, what the filed flight plan(s) were, the cleared route, and the sequence and content of any route revisions. The order of events is a key to understanding what happened. For example, a common occurrence was that the flight plan the crew flew did not match the ATC clearance and the NAT SG analysis can review these events in detail. This might happen for a number of reasons, such as:

- The original flight plan clearance was not entered correctly. The flight was cleared as filed, but the route error remained in the FMS. Sometimes the error in the route is far along the route. It is latent until the flight actually goes off the cleared route. Such latent programming errors are often associated with ATC Preventions.
- The crew received a revised clearance, but entered it incorrectly. Some possible explanations (gathered from real events) include:
    - Using CPDLC, the crew did not notice the extra pages of the clearance.
    - The crew forgot to load the revised clearance (due to time pressure, distractions, etc.).
    - The crew failed to review the revised route (due to time pressure, distractions, etc.).
    - Crew were unaware that the clearance changed, so they missed it.
    - Crew checked the new clearance, but did not notice any change(s), so they assumed there were none.
    - Crew misinterpreted or misread the revised clearance.
    - Crew updated part of the original flight plan route, but not all of it.
    - Crew response says they were impacted by workload, fatigue, distractions, etc.
    - Crew response says they are unsure what happened, even as the event occurred.
- It is also possible that the route programmed FMS is neither the cleared route, not the filed flight plan. For example, Dispatch may have updated the filed flight plan, but the crew did not receive the update for some reason.

The NAT SG has experts in the room to analyze the deviations. Their review improves the quality of the data significantly and is an important precursor to further analysis. Without this review, it can be difficult to analyze the events because of inconsistent or incomplete data. The cases are complicated, and many different pieces of data affect the overall interpretation of the event (as seen in the list above and in the detailed examples in Appendix A). The operator response is especially important for understanding the crew's actions. Our recommendation is to analyze data further only after it has been processed by the NAT SG.

Even with all the expertise, preparation, and discussion, unfortunately, there may not be enough information to know what exactly happened on the flight deck during a specific deviation. The latest version of the NAT SG Handbook (2019) now includes a category for "unknown" human error, acknowledging the ambiguity of some events. We have little contextual information about the actions and rationale of the flightcrew during a lateral deviation. We only know the outcome (a deviation or potential for deviation), and that the crew failed to detect the route discrepancy. Without details on the flightcrew rationale, we can identify what happened as a result of the error (the "outcome") but cannot always say why the error occurred. And without knowing why the error occurred, it is difficult to propose an effective mitigation.

One issue with the current human error classifications, such as Action, Perception (see Section 5.2.3), is that they are not specific to particular mitigation strategies. We also observed that there can be some debate over which human error category should be applied. For example, is the double-longitude error (described in Section 3.5) an action or perception error? A case can be made either way. Another issue is that these categories do not identify errors such as slips and confirmation bias. It would be helpful to call out such errors because they are not easily mitigated through pilot training or system design, and instead, may need to be addressed with independent cross-checks.

8.1.2 Volpe Analyses

Volpe Center and the NAT CMA used different error classification schemes, but both were based loosely on information processing models for the task of handling route clearances. The NAT SG event categorization scheme is broader than Volpe's scheme. It covers more tasks (e.g., coordination between different ANSPs) and people (ATC and flightcrew).

We actually tried two different type of analyses. The first analysis was performed on data from 2017. We proposed a cognitive task-model of FMS related tasks. This scheme is specific to the flightcrew task of route entry and verification using the FMS. For example, the cognitive task model distinguishes between misreading a clearance (*misperception of clearance*) and misreading the waypoints in the FMS (*error in avionics use*). The NAT SG classification system may categorize both as errors of Perception. Similarly, the Volpe Center model distinguishes between failing to look at the entire clearance (*incomplete reading*), failing to enter a clearance into FMS (*non-entry of clearance*), and a "fat-finger" error when entering the clearance (*entry slip*). The NAT SG classification system may categorize all of these as *Actions*. Unfortunately, limitations on the information we have about flightcrew actions and rationale restrict the utility and depth of a conceptual classification of lateral deviations in the NAT.

We also tried an alternative analysis method, a behavioral error classification scheme, on data from 2018 and 2019. This analysis presented a different view of the events. We applied this method to data that had already been reviewed by the NAT SG. It was a relatively straightforward scheme assuming that the events were properly filtered (i.e., pre-processing removed events that were clearly unrelated to waypoint coordinates). As such, the analysis did not require much data interpretation. However, this functional analysis has limits because it does not consider the order of events. We can only know how the flight plan and cleared routes differed. We do not know when the error was introduced or why, limiting our ability to propose mitigation strategies.

8.2 Mitigating Lateral Deviations

Lateral deviations are complicated events that reflect the behavior of humans and technologies across multiple actors (ATC, flightcrew, dispatch). It takes time, expertise, and high quality, high detail data to understand the time-series of an event. And, lateral deviations are not usually single-points of failure. It can be hard to determine how far back to go in the chain of events to get to the root cause.

Our analyses of events from 2017 and 2018 show that they are low frequency events with a variety of potential root causes. Mitigating lateral deviations is therefore challenging. Ideally, mitigations would be developed to address root causes (e.g., misreading the clearance, or not reading the full clearance), not proximal causes of errors that are most easily observed (e.g., flying the flight plan instead of the clearance). If the root cause is not addressed, the solution may not be effective. For example, naming unnamed waypoints would not resolve the issue of not reading the full clearance. Other examples of errors, potential root causes, and potential mitigations are provided in Table 12, which examines issues surrounding flightcrew review of revised clearances. Some of the potential mitigations are changes to flightcrew training or procedures, while others are changes to the technology or system design, such as message format or display design.

In addition to analyzing a complex event such as a lateral deviation that occurred in the past, we have to realize that NAT operations are continuously evolving. Procedures and guidance documents are evolving. New technologies are being introduced. New pilots trained and introduced to the regions operations. The variety of operators, their specific training, and their specific flightcrew procedures is large. So, understanding a problem that occurred last year is just one task; we must also anticipate and predict how the human performance will evolve as the system operations, procedures, and technology change. Mitigations that may help at one point may not be necessary in the future. And, because of the low frequency of events, it may not be possible to assess whether a mitigation was effective or had any impact at all.

Table 12. Example errors, possible root causes, and potential mitigations associated with flightcrew review of revised clearances.

Crew Error	Detailed Description	One Possible Root Cause	Potential Mitigation
Incomplete reading of revised clearance	The flightcrew did not read the entire revised clearance, so they failed to see some (or all) of the differences between the planned route and the clearance.	The crew may not have read the entire revised clearance because of the message format. For example, sometimes the Datalink route message has a line mentioning a change to the altitude. But, the crew may have only noticed the change that was highlighted and missed that the entire route was amended.	Improve the format of the Datalink or CPDLC message.
Misperception of revised clearance	The crew thought the revised clearance matched the planned route, and failed to see a difference (e.g., a single digit changed).	The message formats for the revised and planned routes were visually very similar.	Visually highlight the differences between the revised route and the original (e.g., with bold or large text).
Misunderstanding of revised clearance	The crew read the revised clearance fully, but misunderstood a portion, and therefore did not recognize a difference between the planned route and the clearance.	Possibly, part of the revised clearance was explained on a different page (as part of a longer CPDLC message).	Improve pilot training in reading CPDLC route clearances.
Non-entry of clearance (failed to enter revised clearance)	The crew intended to update the planned route but did not.	The crew failed to enter the revised clearance due to interruptions or distractions.	Improve crew training related to task management.
Error in avionics use	When checking or entering the revised route in the FMS, the flightcrew believed they entered the revised route correctly, but there was an error they did not notice.	The crew may not have expanded the waypoint coordinates to notice a discrepancy between the cleared and planned route.	Improve flight deck displays to support route error checking.

Even with all these caveats, it is useful to identify all possible mitigations, and to assess their potential benefits and cautions. We describe three types of mitigations. First, there are mitigations to flightcrew procedures. Such mitigations are the first line of defense in that they are the quickest to disseminate and are, relatively speaking, low cost. We discuss flightcrew procedure mitigations in Section 8.2.1. Second, there are potential changes to the design of flight deck displays and systems. We discuss these in Section 8.2.2. Finally, there are changes that could be made to the design of the oceanic airspace, including the potential strategy of naming unnamed waypoints, which we consider in Section 8.2.3. Our final recommendation is in Section 8.2.4.

8.2.1 Flightcrew Procedure Mitigations

NAT Doc 007 (2020) describes and recommends several flightcrew procedures designed to mitigate lateral deviations (see Section 3.2 in this report). However, pilots sometimes fail to use these strategies. The strategies are repetitive and take time. And errors 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. (Software solutions may be a better solution for tasks requiring vigilance.) 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. Errors of human fallibility, such as slips, transposition errors, and possibly the "double-longitude waypoint insertion error" 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, that is not a useful point of view because it disregards normal human variation in task performance.

8.2.2 Flight Deck System Design Mitigations

Changes to flight deck system software may help to support human error checking and recovery from route-related errors. These changes are difficult because they may require updates to a large variety of systems and individual aircraft, many of which are older but still in use. There are costs associated with these upgrades, in terms of developing standards, testing and evaluation, and deployment. There may be other costs associated with pilot training as well.

One option is to improve the ARINC 424 Paragraph 7.2.5 convention for waypoint naming. As discussed in Section 3.4, the current naming convention is prone to human error. The first attempt at improving this naming convention resulted in the NAT Hxxyy convention (NAT OPS Bulletin 2018_003, 2019c). However, even this revised convention is only a partial, interim solution. Its effectiveness is untested, and it has a known drawback that many types of aircraft require extra steps to expand the waypoint coordinates with such custom waypoints. Some of the operators we interviewed even stated that they discouraged the use of the Hxxyy waypoints.

Another option is to develop flight deck software to help pilots identify differences between the cleared and programmed routes, as suggested in the IATA latitude-entry case study (2011). This would require the on-aircraft software to have some knowledge of the cleared route. However, it may not be necessary for the software to know the full route; a route code perhaps created from a hash table, or other method might be feasible.

It would also be helpful for pilots if the flight deck systems made it easier for them to view the expanded waypoint coordinates. The current method requires only one step on some avionics, but other avionics require as many as five or six steps, which is too cumbersome for practical use. The process needs to be quick and efficient since pilots are asked to do it multiple times over the course of the flight operation.

Another potential mitigation involving flight deck systems is to modify the ND and CDU components of the FMS to be able to show the full waypoint coordinates. This will not help pilots if they do not use these displays to verify the route, but it might help when the pilot does look at these displays.

8.2.3 Mitigation by Naming Waypoints

From the beginning of this research, one of the questions the FAA had was whether naming unnamed waypoints in the NAT would prevent (or reduce) lateral deviations associated with half-degree waypoints. To do this, a naming convention would need to be developed, tested, and evaluated. Once the naming convention was accepted, the names would need to be published and distributed to pilots, dispatchers, and ATC. Training for all these users may be required. This transition would take extensive planning and coordination.

Based upon our analysis of lateral deviations, the potential benefit of naming unnamed waypoints is that named waypoints might improve error detection during route review and verification. As such, this could reduce errors associated with translating names for waypoints between different systems and users, and it could mitigate the potential for waypoint label ambiguity. This solution might also relieve the pilot of the workload in expanding waypoint coordinates.

However, there are many cautions to keep in mind. The most obvious hurdle is that developing an effective naming convention is not easy, as demonstrated by the studies of human factors issues associated with the NRS waypoint naming convention. Even though some human factors issues with the design of the NRS waypoint names were anticipated, some (e.g., geographic awareness) were not adequately addressed in advance. Learning from the lessons of the NRS waypoint naming convention, we can identify many criteria that a new naming convention would have to meet, including testing with different stakeholders (such as ATC, pilots, dispatchers, chart manufacturers, and avionics display manufacturers). The naming convention has to be evaluated by pilots and ATC in terms of:

- Ease of data entry (e.g., time for pilots to enter the names manually, and error rates)
- Phonetic confusability with a voice clearance delivery method
- Visual confusability with a written/visual clearance delivery method such as CPDLC or ACARS
- Ease of conveying geographic awareness

In addition to developing an effective naming convention, the scope of the naming convention must be considered. How many waypoints would be named? Will the named waypoints be easily stored on existing FMS databases (many of which are close to full already)? Could the names be compressed for smaller storage needs?

A new naming convention also would need to be flexible to accommodate potential future changes, such as the widespread use of SB ADS-B. For example, the NRS naming convention was designed to be expandable because it was anticipated the grid structure would become finer, with more and more waypoints. And, the new naming convention needs to be intuitive and consistent *across world-wide use*, not specific to just the NAT. Although the NAT is currently the densest oceanic airspace, it is important to anticipate world-wide operations.

Even if a good naming convention is developed and meets all the criteria mentioned above, we know from our analysis of lateral deviations that naming waypoints does not prevent all errors; there are several cases with in the dataset of deviations that occurred with named waypoints. And, as is often the case with human error, it is likely that named waypoints will introduce different types of errors, which still need to be addressed.

Finally, our analyses showed that the lateral deviations associated with half-degree waypoints were only a small proportion of the overall lateral deviations. Errors associated with flying the flight plan instead of the clearance, or incorrect insertion of waypoints were far more common. The overall benefit of naming waypoints will be limited because this solution would address relatively few situations.

8.2.4 Recommendation

The NAT Doc 007 (2020) and other NAT guidance documents have several good recommendations for flight deck procedures related to oceanic route review and operations with half-degree waypoints (see Section 3.2). These recommendations should be followed and disseminated broadly. However, it takes time for pilots to learn all the strategies. There should be adequate practice. We have no further recommendations related to mitigating errors associated with half-degree waypoints. The data analysis did not establish common causal factors other than what are already addressed in the existing guidance. Further potential mitigations, such as those discussed above, could be explored if desired.

8.3 Implications for TBO

There are several initiatives under the FAA NextGen program designed to modernize air traffic management in the US. One major initiative is the development of 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." (FAA, 2016b). Unnamed waypoints, including those with half-degree coordinates, could be building blocks for dynamic routes in TBO.

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, especially for any new unnamed waypoints.

TBO routes might 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. We do not know of a current assessment on the usage rate for NRS waypoints. How will FMSs and their navigation databases handle a potentially large number of new waypoints for TBO? What size of database will an FMS need with TBO? If a new naming convention is required, that will be a significant area for development and evaluation.

Another finding of our analysis of lateral deviations is that deviations are more common for Random routes. Random routes are more desirable for operators 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. It may be useful to consider whether TBO should include a route structure similar to the OTS over the CONUS.

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.

8.4 Suggestions for Additional Research

The main focus of this research was to understand human factors causal factors for lateral deviations involving half-degree waypoints in the OTS. We expanded this limited goal by exploring human factors causes of all lateral deviations across the NAT Region, including those on Random routes. We were unable to determine why Random routes have higher rates of lateral deviations than OTS routes. This would be an area for further research. Similarly, we did not have access to exposure rates (how often half-degree waypoints were issued) versus the rate of associated lateral deviations relative to whole-degree waypoints. It would be interesting to gather these exposure rates to understand whether there are any differences in terms of rates of lateral deviations with and without half-degree waypoints. If the recommended flight deck procedures are used effectively across all types of routes, we would expect that half-degree waypoints would not be associated with higher rates of lateral deviations.

From a human factors perspective, we found that it was often difficult to find definitive evidence of errors caused by half-degree waypoints. That leaves us with a general recommendation that flightcrews should follow established guidance. However, we did not explore whether there are sufficient opportunities for crews from all types of operators (foreign carriers, US carriers, military, charter, and general aviation) to receive high quality, effective training. While the NAT Region documents are clear and informative, pilots may not read these documents on their own, relying instead upon training from their employer or a third party.

One final suggestion for related research is to explore potential issues related to conditional lateral clearances given via CPDLC. Previous research has found that complex CPDLC conditional vertical clearances (with conditions on when the altitude change is allowed to begin) can result in altitude deviations where flightcrews begin the altitude change early (Chandra, Lennertz, and Cardosi, 2019). We conducted an exploratory analysis of conditional lateral clearance CPDLC messages issued in the New York East Oceanic airspace from 2015-2017. However, these messages were used infrequently, and we could not discern a relationship between these messages and lateral deviations. Future work could expand this analysis to study a larger message set, additional route deviation data from US oceanic airspace, and a broader context of the messages exchanged between pilots and controllers.

9 Conclusion

This project sought to understand flight crew causal factors in lateral deviations involving half-degree waypoints and, based on this understanding, to propose mitigations for these causal factors that might enhance the guidance in NAT Doc 007 (2020). Based upon a review of related literature, an analysis of lateral deviations involving half-degree waypoint coordinates, and informative conversations with NAT operators, we conclude that the available guidance, in NAT Doc 007 and other NAT Region guidance documents, does address potential deviations related to half-degree waypoints.

In particular, the guidance to expand the full waypoint coordinates multiple times, if followed, helps crews to catch errors where half-degree or whole-degree coordinates are unintentionally entered into the FMS route. The number of lateral deviations that still occur related to half-degree waypoint coordinates is small relative to the other causes of lateral deviations (NAT ASR 2018, 2019b). But, expanding waypoint coordinates multiple times is not an optimal procedure for flightcrews. It is a vigilance task that is prone to error. Crews may not see the value of this procedure, especially if it is cumbersome and if they rarely detect route errors using it. The naming convention for half-degree is also not optimal, but the costs of developing, testing, and implementing a better convention will be significant.

The lessons learned from NAT operations using half-degree waypoint coordinates can be applied to the development of NextGen TBO. Similar to the NAT Region, TBO may eventually support Random routes that incorporate unnamed waypoints defined by their coordinates, including half-degree coordinates. It will be important to apply the lessons learned from lateral deviations in the NAT to proactively address these issues for TBO.

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Appendix A: Details of Events Involving Half-Degree Waypoints

There were ten events in 2017 that had half-degree latitude waypoints in either the clearance or the route in the FMS. Seven of these events were GNEs, one was a Prevention, one was an ATC intervention, and the last one was a lateral deviation less than 10 NM. Of the seven GNEs, three were on the OTS and four were on Random routes. For these specific 10 events we independently reviewed the supporting materials that were available to the NAT SG. We did not search for events in 2017 that had either half-degree longitude or partial degree waypoints.

The events are presented in three tables below, separated by the type of evidence for problems related to waypoint labels. Table 13 describes two GNEs where there was some involvement of half-degree latitude waypoint labels. The first was a case of display label ambiguity due to truncating/rounding and the second was a translation error across systems/users.

Table 14 describes four events where there was insufficient evidence to draw a conclusion about the impact of the half-degree latitude waypoint labels. Three of these were GNEs, and one was a Prevention. One of the GNEs was a possible case of a double longitude entry error. The other two GNEs had insufficient detail to determine the error type.

Table 15 describes four events that were definitely unrelated to half-degree latitude waypoint labels. One of these was a GNE, and this was caused by a failure of the navigation system, unrelated to half-degree waypoints.

We reviewed in detail all cases for 2018 that had any half-degree waypoints (either in latitude or longitude), but found no cases after June of that year. There were 11 events total, four GNEs and seven Interventions. Five of these involved half-degree latitude waypoints, four involved half-degree longitude waypoints, and two had partial-degree waypoints. All of these were on Random routes, none were on the OTS. All were within the HLA. We also reviewed the events between July and December 2018, but there were none involving half-degree latitude or longitude waypoints in the second half of the year, so our analysis does cover all events in 2018. All of the 2018 events with half-degree latitude waypoints had flights that were given revised clearances and the waypoints were not updated correctly.

The data for 2018 are presented in Table 16, Table 17 , Table 18, and Table 19. These tables also show how the NAT SG classified the event. Recall, however, that if the “Truncated Display” issue was assigned, that does not necessarily mean that it was a factor in the event, only that it was present. Table 16, describes three events with some evidence of a waypoint label issue. Table 17 describes two inconclusive events. Table 18 describes four events with half-degree longitude waypoints. Three of these were unrelated to the half-degree waypoints, and one had insufficient evidence. Finally, Table 19 describes two events with partial-degree (but not half-degree latitude/longitude waypoints). One had insufficient evidence to draw a conclusion, and the other had some evidence of a double entry of the longitude into the latitude.

Data for the four Interventions between January and June 2019 are presented in Table 20. Two of these cases showed some evidence of a waypoint display label factor and the other two were unrelated to the waypoint display label.

Table 13. Two lateral deviations in 2017 with <u>some involvement</u> of half-degree latitude waypoint labels.

2017 Event Date and Code	Summary and Discussion	Type of Route	Max Deviation	Cognitive Task Error
18 January L/17/01/03/B	Flight was cleared on the whole-degree Track B. Aircraft flew north of cleared route towards 5230/20 instead of 52/20 on Track B after LIMRI. The half-degree track (Track C) included 5130/20, so the aircraft deviated away from half-degree track, not towards it. The error occurred just after entering the oceanic airspace. Crew was unaware of the deviation; they thought they were on the cleared route. ATC eventually re-cleared the aircraft for their flight plan route, which was off by just the one waypoint; other waypoints were correctly entered as whole-degrees. Operator feedback says that the crew selected the whole-degree waypoint route, but they used the 52N020W waypoint that was already in the database, and this name was assigned to the half-degree waypoint. The operator lists causal factors as: 1) naming convention for FMS waypoint, 2) Crew did not verify the expanded waypoint, 3) FMS display label limited to (ambiguous) 7 characters. However, there was no direct input from the crew. Also, the crew may not have thought to expand and check the waypoint coordinates if they thought they were on the cleared (whole-degree) track. *This case has some evidence for degraded error detection with half-degree waypoints. The causal factor was that the avionics display label was pre-defined and unclear. Waypoint label was a factor. The 7 char name the crew selected was assigned to a half-degree waypoint, and available in the database. The crew thought it was a whole degree waypoint based on the label, and did not expand the coordinates.*	OTS	24 NM GNE	Crew confusion, misperception, misinterpretation or misuse of avionics. Degraded error detection due to abbreviated 7-char waypoint label.
2 October L/17/10/01	Private operator used a vendor's system to generate a flight plan. It created waypoints named 5950N H6140 H6230 6320N. These names were not recognized by another software vendor, which filed the route, so the waypoints were filed as whole degrees instead of half-degree waypoints. Crew did not catch the error during route verification. *There is some evidence of a "translation" error, but by the software, not by the flightcrew.*	Random	>=10 NM GNE	Crew saw/heard correct clearance, but misinterpreted or mis-translated it on entry Translation error.

Table 14. Three lateral deviations in 2017 with <u>insufficient or inconclusive evidence</u> for involvement of half-degree latitude waypoint labels.

2017 Event Date and Code	Summary and Discussion	Type of Route	Max Deviation	Cognitive Task Error
12 October L/17/10/02	Military flight, just one waypoint was flown half-degree off. No operator response or other details. *<u>Insufficient detail</u> to know whether the error was related to half-degree waypoints. Cannot determine whether waypoint labels were a factor.*	Random	30 NM GNE	Entered flight plan was not updated to match clearance for unknown reason.
15 May L/17/05/06/B	Aircraft cleared on Track D (whole degree, just south of Track C), but tried to join Track C (half-degree track, which was the flight plan route). ATC received a conformance alert based on the NEXT waypoint information 5 minutes before the deviation began after the oceanic entry point. Aircraft returned to cleared track. *<u>Insufficient detail</u> to know whether half-degree waypoints were a contributing factor. Cannot determine whether waypoint labels were a factor.*	OTS	11 NM GNE	Crew saw/heard correct clearance, but misinterpreted or mis-translated it on entry.
14 July P/17/07/03	Cleared on whole-degree track south of half-degree track, but aircraft was on the half-degree track. ATC identified the error early, and the track did not result in a GNE. *<u>Insufficient detail</u> to know whether half-degree waypoints were a contributing factor. Cannot determine whether waypoint labels were a factor.*	OTS	Prevention	Crew confusion, misperception, misinterpretation or misuse of avionics.

Table 15. Four lateral deviations in 2017 with <u>no</u> involvement of half-degree latitude waypoint labels.

2017 Event Date and Code	Summary and Discussion	Type of Route	Max Deviation	Cognitive Task Error
25 May L/17/05/03/B	Flight joined the half-degree route (which was in the flight plan) incorrectly after the entry point. Flight was cleared for whole degree (random route) south of the half-degree track, which had a different entry point. Crew said the updated clearance changed the entry and exit points, which they had noted were unusual in the flight plan. They confirmed these points, but did not notice the entire route was amended. The revised route had all whole degree waypoints.	Random	15 NM GNE	Crew did not look through entire clearance and missed part of it.

2017 Event Date and Code	Summary and Discussion	Type of Route	Max Deviation	Cognitive Task Error
7 July L/17/07/03	Aircraft lost FANS connection and was rerouted to de-conflict with traffic on RLatSM track. The revised clearance was issued late and the crew was busy with communication tasks, so they failed to enter the first revised waypoint in time.	OTS	58 NM GNE	Crew knew of clearance but didn't enter it.
24 July L/17/07/09	Intentional deviation due to weather.	OTS	< 10 NM	Filtered out of dataset.
18 October I17/10/02	Mis-entered 4930 as 4939.	OTS	Intervention	Crew made key entry slip, and did not notice on cross-check.

Table 16. Three lateral deviations in 2018 with some involvement of half-degree latitude waypoint labels.

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
9 March I180301 Commercial	The flight planned route had only whole degree waypoints. The flight was cleared on a different route (also with only whole degree waypoints), and the crew updated the FMS route, but incorrectly. The crew mistakenly entered two half-degree latitude waypoints at the whole degree latitudes (with the same digits). When asked to confirm the route via HF communication, the crew reported the correct cleared route, so they were unaware of the half-degree latitudes in the programmed route. *Some evidence that waypoint labels were a factor in the deviation.*	7 NM Intervention	• Waypoint(s) in flown route not updated correctly • Truncated display issue • Perception
29 June I180605 Commercial	The original flight plan did not contain half-degree waypoints. The crew received a revised clearance, which they entered incorrectly. All waypoints (at 20W, 30W, 40W and 50W) in the revised route were off by half degree in latitude. When queried by ATC (via HF), the crew read back the correct ATC clearance, but their position reports still showed the half-degree latitude positions. ATC explicitly asked crew to check expanded coordinates, after which the route was corrected. *Good evidence that waypoint labels were a factor in the deviation.*	4 NM Intervention	• Waypoint(s) in flown route not updated correctly • Truncated display issue • Action

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
24 June I180604 Commercial	The crew received a revised clearance from ATC late (due to ATC equipment failures). They noticed the change to the oceanic entry point, but did not have time to check the route in the FMS because they were being given vectors and altitude changes to reposition for the oceanic entry point. After ATC query, crew discovered they had entered N4920 instead of 4920N, and this had gone unchecked due to workload. *While the crew did confuse the waypoint labels upon initial entry (likely a slip), the lack of review that was a more significant factor than the waypoint label.*	7 NM Intervention	• Truncated display issue • Waypoint(s) in flown route not updated correctly • Other – Equipment • Perception • *Crew and ATC workload were key factors (due to ATC equipment failures) that day.*

Table 17. Two lateral deviations in 2018 with <u>insufficient or inconclusive evidence</u> for involvement of half-degree latitude waypoint labels.

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
19 January L180106 Private	After ATC query, pilot said he was following his flight plan route (which had two half-degree latitude waypoints) instead of the clearance (which had only whole degree waypoints, one at a different longitude too). The pilot said he/she received the clearance but gave no explanation as to why the cleared route was not programmed in the FMS. *<u>Insufficient evidence</u> because pilot does not mention whether he/she attempted to verify the cleared route in the FMS.*	2 NM Intervention	• Flew Flight Plan instead of Clearance • Truncated display issue • Action
3 May L180501 Private	The original flight plan, filed 4 hours before the flight, had three half-degree latitude waypoints. The aircraft was cleared on a route with only whole degree waypoints, (with the same digits). The flown route had one half-degree latitude waypoint, so two of the waypoints were corrected, but one was not. *<u>Insufficient evidence</u> that waypoint labels were a factor. Two of the three waypoints were corrected and the third waypoint was not, for unknown reasons.*	30 NM GNE	• Flew Flight Plan instead of Clearance • Truncated display issue • Action *Waypoint updating may also have been a contributing factor.*

Table 18. Four lateral deviations in 2018 involving half-degree longitude waypoints. All of these events occurred at the boundary of the Reykjavik and Shanwick FIRs.

Note: I180402 and I180504 had similar issues, but were with different commercial operators.

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
17 January I180101 Military	The flight plan matched the clearance. Both had the waypoint 61N01330W between PETUX and ORTAV, but the flown route was a direct path between PETUX and ORTAV, as though 61N01330W were deleted. There is no operator report. *Insufficient evidence that waypoint label was a factor.*	4 NM Intervention	• Crew Other • Action
6 March L180301 Commercial	The flight plan included a waypoint at 16N1630W. The clearance amended the flight plan, changing this one waypoint, to 16N16W. Upon ATC query, the crew confirmed the routing through 1630W. The crew also reported that they did not load the updated clearance. *Unrelated to half-degree waypoint. The crew did not load the revised clearance and used the default company flight plan.* This operator had three similar cases in 2017. The company route has since been changed to use 16N16W.	11 NM GNE	• Flew Flight Plan instead of Clearance • Truncated display issue* (assumed) • Perception
4 April I180402 Commercial	The flight was cleared on its flight plan, which did not contain a half-degree longitude waypoint. However, inflight, the crew reported following a different route, passing through two other waypoints, one whole degree, and another at a FIR boundary at 61N1630W. No operator response and no reroute. *Unrelated to half-degree waypoint. The flown route had two wrong waypoints, one with whole degree coordinates and one with a half-degree longitude.*	5 NM Intervention	• Waypoint(s) in flown route not updated correctly • Action

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
19 May I180504 Commercial	Crew mistakenly added two waypoints to their cleared route, one of which was 61N01630W. Crew realized the error upon ATC query and corrected their route. No further operator response. All HF communications. *<u>Unrelated to half-degree waypoint.</u> The flown route had two wrong waypoints, one with whole degree coordinates and one with a half-degree longitude.*	2 NM Intervention	• Flew Flight Plan instead of Clearance • Action

Table 19. Two lateral deviations in 2018 involving partial-degree waypoints.

2018 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
January 3 L180102 Commercial	ATC observed flight going off course (towards a waypoint with a partial-degree latitude and a partial-degree longitude, 6215/4149). ATC queried crew if there was weather. Crew said there was no weather. Crew said they found the problem and rectified, without any other information. *Insufficient information, but not likely to be related to display labels since the partial degree waypoint was inserted in the route without explanation, and the corresponding whole degree values of the wrong waypoint (62/41) were not in either the cleared or flight plan route.*	40 NM GNE	• Other • Action
June 9 L180601 Private	ATC observed the flight 30 NM off course and asked crew about it. Crew took some time to identify the problem because the error was an incorrectly entered user-defined waypoint (6140/40 instead of 6140) and the error was copied to both GPS systems. *Possible double-longitude entry of a user-defined waypoint, but the error was made by a "technical team member" who created the flight plan, not the flightcrew. The crew likely did not verify the expanded waypoints. The operator says it has updated process for uploading flight plans and amended flight deck procedures to ensure that the flightcrew verifies waypoints.*	40 NM GNE	• Waypoint(s) in flown route not updated correctly • Action

Table 20. Events involving half-degree latitude or longitude waypoints from January to June 2019.

2019 Event Date, Code, and Type of Operation	Summary and Discussion	Max Deviation and Event Type	NAT SG Contributing Issues and Crew Error Classifications
31 May I/19/05/01 Commercial OTS	The flight planned route was Track C (half-degree track) in the OTS, a track with half-degree latitude waypoints. The flight was cleared on Track D (whole-degree, just south of Track C). It appears that the flight planner did not update the route, and the crew did not notice the revised clearance in their checks. At least two waypoints were entered incorrectly in the FMS as half-degree latitude waypoints. *<u>Some evidence</u> that waypoint labels were a factor in the deviation.*	9 NM Intervention	• ATC - Pertinent Message Not Actioned • Crew - Truncated Display/ARINC 424 • ATC – Action • Crew - Perception
8 June I/19/06/03 Commercial Random Route	In the operator response, crew says they manually entered incorrect waypoints during period of high workload, possibly due to waypoint ARINC 424 naming convention (prefix-suffix) confusion. At least two waypoints were entered incorrectly in the FMS as half-degree latitude waypoints. *<u>Some evidence</u> that waypoint labels were a factor in the deviation.*	1 NM Intervention	• Crew - Truncated Display/ARINC 424 • Other - Equipment - Airborne • Crew - Workload Management
8 June I/19/06/02 Commercial Random Route	Crew was given a revised clearance through CPDLC, but the crew said during the event that did not notice the portion of the route after the VIA, so they did not upload the new clearance. In the US there would be a free text warning to the crew to load the clearance, but this not the case internationally. *<u>Unrelated to half-degree waypoint.</u> The crew did not notice the revised clearance.*	3 NM Intervention	• Crew - CPDLC Uplink Messages • Crew – Perception
23 January L/19/01/05 Commercial Random Route	In the operator response, crew says they decided not to reprogram the FMS route because they thought the half-degree longitude waypoint in their flight plan was along the revised route. Only one waypoint was modified in the revised clearance. *<u>Unrelated to half-degree waypoint.</u> The crew did not load the revised clearance and used the flight planned route instead.*	6 NM Intervention	• Crew - Flight Plan vs. Clearance • Crew - Decision Making

Appendix B: Operator Flight Deck Procedures

Aircraft Types in the sample of respondents

- B-787, B-777, B-757, B-737, B-767-ER, B-767-400, B-767-300
- A-330, A350
- Gulfstream 550

EFB hardware and software in the Sample of Respondents

- Panasonic Toughbook with electronic charts and a plotting application.
- iPad with Jeppesen FliteDeck (FD) Pro

Typical Routes

	Typical Routes
Passenger	• 90% on random routes. These are "preferred" operational routes and are often repeated. They may be on the track for part of the preferred route. • 10% on NAT OTS or Pacific OTS. • Routes do not use half-degree waypoints regularly. • Do not fly on PBCS due to a training issue, not an equipment issue. PBCS requires an authorization from the relevant civil aviation authority, and the local authority is not familiar with the process yet.
Passenger	• All flights are oceanic • Only fly random routes. Almost all use whole degree waypoints. • Do not fly OTS routes. • Have company routes stored on FMC. Use a few half-degree waypoints.
Passenger	• Approximately 50% OTS, 50% random routes.
Cargo	• Use mostly random routes because of off-hour operations • Most routes are whole-degree waypoints • Have filed half-degree routes, but not commonly used • As a freight carrier, not as concerned about ride quality. Just fly the requested altitudes.
Passenger	• More often on OTS than random routes. • Route depends on departure, destination and winds. (For example, a light 787 can get above the OTS routes.) • Used RLatSM. Did not discuss PBCS.
Corporate	• Usually on random routes above the track system for better winds. • Random route might follow the track system for a few waypoints. • Also fly on "Blue Spruce" routes which are over land for much of the Atlantic • Do not fly RLatSM.
Passenger	• 60% flights on OTS (higher use of OTS than other airlines) • 40% on Random routes • PBCS and RLatSM routes. Use half-degree tracks. • Sometimes fly a route with a mix of track and random segments

Technology on Aircraft

	Technology on Aircraft
Passenger	• Have CPDLC, ADS-B, and ADS-C. • The ND can show only waypoints on the route. At 40 mile range and lower, it can show other nearby waypoints. Maximum display range of 1300 miles.

Passenger	• Some do not have CPDLC. (Will have it next year.) Others do have CPDLC.
	    • Do not have mitigation of ADS-C
	    • Do not have route confirmation dialog with CPDLC
	• EFB route is independent of the FMC.
	• The ND has the capability to show waypoints that are not on the flight plan and can create waypoints for display.

Passenger	• All are FANS equipped (CPDLC, ADS-C and ADS-B Out). • EFB is an iPad with Jeppesen FliteDeck Pro with data-driven enroute oceanic charts. • More than 80% of flights are PBCS approved, almost all will be approved by March, 2019
Cargo	• All have CPDLC, ADS-B, and ACARs. • Majority are already FANS 1/A. All will become FANS 1/A over next year. • Certified for PBCS, but not utilizing full capabilities. • Upgraded primary flight deck displays (not legacy). • Use an iPad EFB, mounted separately. Jeppesen FliteDeck Pro. Has an enroute moving map over the ocean. No custom applications for oceanic operations. • Can show (individual) waypoints that are not on the flight planned route on the ND by entering them in the FIX page of the CDU.
Passenger	• Have ACARS, ADS-C, RLatSM • “Autload” of route from CPDLC is available on some aircraft but not all. • With CPDLC, pilot must load, check and then either respond with either ACCEPT, REJECT or STANDBY. After sending ACCEPT, pilot still has to EXECUTE the route in the FMS. • ND has a range of up to 1080 NM
Corporate	• Honeywell Primus Epic System, PlaneView. • Has a Vertical Situation Display and shows traffic. • CPDLC, RNP4, ADS-C compliant. • GA does not use ACARS, talk to ARINC operator or ATC directly. • Printer in flight deck to print out CPDLC clearances.
Passenger	• All CPDLC over the NAT. • Almost 100% aircraft on PBCS compliance. • Almost 100% ADS-B out • A few with ADS-B in. Will grow in time. • EFB with Jeppesen FliteDeck Pro. • Can show all published waypoints but not NAT latitude/longitudes (unnamed waypoints). • Tracks can be displayed on the EFB (JeppView FliteDeck Pro).

Waypoint naming convention(s) used

	Waypoint Naming Convention(s) Used
Passenger	• 5-letter ARINC 424 Paragraph 7.2.5 conventions ("N" in the NAT and "E" in the Pacific) • 7-character latitude-longitude convention.

Passenger	• Use 7-character label, full coordinates. Also have ARINC 424 Paragraph 7.2.5 and the Hxxyy format on the same system. Pilots understand all conventions.
	  ◦ With half-degree waypoints, uses Hxxyy if the waypoint is in the database.
	  ◦ If pilot or dispatch creates the waypoint on a particular day, FMS will use the N convention.
	• The flight plan can use all three waypoint name formats (7 character ICAO format, Hxxyy format, and ARINC 424 Paragraph 7.2.5). Dispatch uses the same waypoint names as the pilots.
	• Some of the waypoints are not in the North Atlantic, and the N is in the middle of the numbers (for West longitudes past 100°).

Passenger	• ARINC 424 Paragraph 7.2.5 format and 7-character (with latitude/longitude).
Cargo	• FMS uses the ARINC 424 Paragraph 7.2.5 convention (e.g., 5030N). Uses N as prefix for half-degree waypoints. (Do not use the Hxxyy format for half-degree waypoints.) • The OFP has full 12-digit coordinates for waypoints.
Passenger	• Use the 7 character format (with latitude/longitude digits) generally. • Hxxyy format names are in the database. Don't use this format on the B-777 in order to avoid extra steps for expanding the coordinates. A330 uses the Hxxyy format. (Expanding the coordinates is one step on this type aircraft.) • Waypoints created with latitude/longitude show up with (5-char) N (ARINC 424 Paragraph 7.2.5) format.
Corporate	• ARINC 424 Paragraph 7.2.5 display labels
Passenger	• Can show either the 5-letter ARINC 424 Paragraph 7.2.5 name, or the Hxxyy format, or the 7-character label.

Flight Planning

	Flight Planning
Passenger	• Airline has its own Dispatch which uses Jeppesen flight planning software. • Operator does not directly load the flight plan into the FMC. • Pilots manually enter a route into the FMC from a paper flight plan issued by Dispatch. The other pilot confirms the entry. The pilots then enter the route into the EFB as well.
Passenger	• In-house Dispatch. • Pilot loads the EFB route from Dispatch pre-flight. • To use the EFB plotting chart, pilot enters the route and current location.
Passenger	• In-house Dispatch
Cargo	• File own flight plans. In-house Dispatch (Type A). • Pilots input flight plan manually into EFB and FMS, do not have upload capability. • Entering the route requires one pilot to enter the coordinates, while speaking them out loud. The other pilot will verify the coordinate before it is executed. • Can receive a CPDLC clearance but not able to upload route into FMS.
Passenger	• *Not discussed. Does have in-house Dispatch.*
Corporate	• Operator has a Dispatch, but it handles logistics, not flight planning. • Pilot manages flight plans and clearances. • Third party computes the flight plan. It is faxed or emailed to pilots 2 hours before flight. Both pilots check the flight plan on the ground. The vendor files the flight plan.
Passenger	• Dispatch uses Sabre software to optimize the route. • Flight planning system does not allow a mix of whole and half-degree waypoints on a random route. • Upload the flight plan to the FMC via ACARS. Crews confirm the route. • Flight plan is not uploaded to the EFB. Request the flight plan via JeppView FliteDeck Pro to show the flight on the EFB enroute (database-driven) charts.

Pre-flight Route Review (on ground)

	Pre-flight Route Review (on ground)
Passenger	• One pilot expands the waypoint coordinates in full in the FMC and reads them aloud. The other pilot confirms from the chart that the FMC entries are correct and checks headings. • Expanding 5-letter names to see full coordinates requires 4-clicks (change pages twice, then search for name and select). It requires just 1-click to expand the 7-letter name. • Pilots are trained to review the (CPDLC) routes independently before accepting, but sometimes this does not happen. Pilots might load the route first, then realize they cannot accept it. • No difference between how OTS and random routes are reviewed. The OTS routes just have the track name (a letter) to check in addition to the waypoints.

	Pre-flight Route Review (on ground)

Passenger	• EFB has the master document for verification and is independent from FMC. This document serves as a checklist of each waypoint that has been verified.
	• If clearance is given by DL instead of voice, both pilots are encouraged to read the DL printout independently before verification.
	• One pilot expands the waypoints in the FMS and reads the waypoint name out loud (e.g., six-five-three-zero-north). The other pilot follows along with the flight plan and checks that each expanded coordinate matches the flight plan.
	    • Reading the waypoint names is time consuming.
	    • There are multiple navigation steps within the FMS to access the expanded coordinate. For every oceanic waypoint, must first select the waypoint on the CDU, then look up navigation data to view the full coordinates.
	    • Must expand waypoint coordinates if it is not named.
	    • There can be as many as 10 waypoints to expand on a random route.
	• Pilots also check the bearing and distance for oceanic waypoints pre-flight.
	• They also check the validity of the navigation database pre-flight. This is an important step.
	• For reroutes: Only re-verify the expanded waypoints for the portion of the route that has been changed, and use the ND to look for any large turns or discontinuities in the re-route.
	• Check TMI for OTS routes, otherwise same process for OTS and random routes.

Passenger	• Printed (paper) OFP
	• First steps of verification occur in the crew briefing room:
	    • Downlink the flight plan to EFBs. (No pilot route entry.)
	    • Each pilot has their own EFB and verifies the route independently.
	    • Verify the route from the EFB against a paper orientation chart.
	• PF initiates the downlink of the flight plan into the FMS. PF verifies full coordinates for unnamed waypoints against the OFP and the EFB.
	• PM also loads the flight (independently) and circles the waypoint on the OFP as each point is verified.
	• Sequential process. PF does his/her tasks, then the PM does his/her tasks. The PM checks the work of the PF.
	• Independent checks; the pilots do not speak to each other.
	• Steps to expand the full latitude and longitude coordinates:
	    o If using full latitude/longitude for the waypoint, expanding takes 1-2 steps depending on type of FMS.
	    o If using Hxxyy format, up to 5 steps to expand coordinates.
	• With 5-letter named waypoint, also up to 5 steps to expand the coordinates. (Same as with ARINC 424 Paragraph 7.2.5 convention.)

	Pre-flight Route Review (on ground)
Cargo	• The expanded check is also done on ground; the reviewing pilot expands the coordinates to check them, this takes either 2 or 3 key presses. To expand the waypoint, put it in the FIX page and compare the FMS coordinates to the 12-digit coordinates in the OFP. • Use EFB as an independent source to check. • Verification on moving map on the EFB. Can see the track entered in the EFB, which should match the FMS and paper OFP. • Standard procedure for all routes, oceanic and domestic • If the route is modified, will expand waypoint coordinates again in the air.

<table>
<tr><th></th><th>Pre-flight Route Review (on ground)</th></tr>
<tr><td>Passenger</td><td>Pilots compare the full clearance and confirm the information displayed in the LEGS page of the FMS.
To check the route, configure the CDUs so that the left one shows the full route clearance and the right CDU shows the LEGS page. Go back and forth between the two CDU's to verify the cleared route is loaded in the FMS.
Do not use the ND to preview the route.
Always expand the full waypoint coordinates during review.
H waypoints cannot be expanded in the scratchpad, pilot must navigate to REF NAV data page. (Extra steps.)
Also expand whole degree waypoints. No difference in procedure.
Check distances and headings.
Pilots do independent checks on every waypoint.
Pilot must review all pages of the (CPDLC) clearance.</td></tr>
<tr><td>Corporate</td><td>For reroute
First compare original flight plan and the printed reroute.
Using the printed reroute, reprogram the FMS or activate the route if obtained through CPDLC.
Verify each waypoint.
Have the ND in Plan mode. Compare the ND route to the route plotted on a paper chart. These are two independent views.
Both pilots check the waypoints using the master document and the flight plan.
Good practice to expand waypoint full coordinates for half degree tracks.
For a regular (whole-degree track), comfortable with short ARINC 424 Paragraph 7.2.5 names (and would not expand the coordinates). But some will expand in case there is a bad database.
Also check distances and headings.</td></tr>
<tr><td>Passenger</td><td>Steps are consistent across fleets (of different aircraft types)
First step is silent, independent review by both pilots, comparing FMS route to clearance
Second step is verification, where one pilot reads or spells out the route and the other draws a mark (circle or line) through the waypoint on the paper master flight plan.
Each waypoint must be expanded in the scratchpad before flight; this takes 2-clicks per waypoint.
Also check distances.
Reroute: Provide pilots with a guide in the format of a checklist on a 1-page hard card. Back of card has track changes and contingency procedures. Must recheck and re-expand every waypoint.
Random routes and OTS routes are reviewed the same way. Also verify the track (letter) with OTS routes.</td></tr>
</table>

In-flight Route Verification (prior to entering oceanic airspace)

	In-flight Route Verification (prior to entering oceanic airspace)
Passenger	• Only expand the waypoint coordinates pre-flight, not in-flight.
Passenger	• Same as pre-flight check, since all flights are oceanic. No time to review the route in flight because the first waypoint is in oceanic airspace.
Passenger	• Usually receive oceanic clearance via ACARS/DL, but could be voice. Will check everything. • Verification is done out loud, with PM reading to the PF. "Challenge and reply" all the way through the oceanic clearance. • First PM reads from printout of the clearance with altitude, entry point, and time of entry. Verify expected time at oceanic entry point on primary flight display. • Next, PM reads off the latitude/longitude for each of the unnamed waypoints. As each one is read out, the PF goes to the FMS and finds the waypoint, pulls it down to the CDU scratchpad. • PF verifies expanded waypoints in the scratchpad. Each point is marked again on the OFP, this time with a hash over the circle (from the first check). The hash mark means "This is our clearance and latitude/longitude has been verified." This is the third time the coordinates were expanded (twice by PF, once by PM). • Secondary track and distance check between waypoints is shown on OFP and FMC. Good practice to check these. • For revised oceanic clearance, both pilots independently verify the expanded coordinates of the revised portion of the route.
Cargo	• Check distances and tracks prior to entering oceanic airspace; one pilot reads of the FMS, track, and distance between two points, the other pilot confirms with the OFP. • If route is amended in flight, pilots verbally confirm the revised waypoint. For example, controller says "Cleared to 50 North 30 West" then one pilot enters the coordinates (5030N) in the FMS, then says "Confirm 50 North 30 West." Then the other pilot says "Confirmed", then they execute the route.
Passenger	• Receive oceanic clearance 30+ minutes before entering oceanic airspace. • Perform another verification with fully expanded waypoints.
Corporate	• Receive oceanic clearance 60 to 90 minutes before entering oceanic airspace, while airborne. • Print, review and accept oceanic clearance via CPDLC. Then reconfirm route by checking the waypoints in the FMS. Replot the paper chart, view the entire route in Plan Mode in ND and compare. • If there is a reroute pilot manually reenters the new flight plan.
Passenger	• Each waypoint must be expanded in the scratchpad *again (second time)* before entering oceanic airspace. • If there is a revised clearance would have to expand waypoint coordinates. Preferred re-clearance is via CPDLC and "autoload." Errors could be introduced with ACARS or voice.

In-flight Route Monitoring

	In-flight Route Monitoring
Passenger	• Mostly use the ND. • Pilots set the range on the ND based on their personal preferences, and for what information they need to see (e.g., weather). • Also use a paper plotting chart for the Pacific and Atlantic. Pilot plots the waypoint when it is passed, about every hour.
Passenger	• Flight monitoring is done using the ND and the EFB. • On the EFB, check a box when the waypoint is crossed. Enter present position from the FMC in the EFB plotting chart application. • Pilots use their own techniques and checks to monitor the flight plan. • Do not require pilots to expand waypoint coordinates as they cross. • Pilot technique for configuring the ND. Usually show navigation aids and waypoints for positional awareness. Also have the Inertial Reference System (IRS) panel display of position.
Passenger	• When approaching a point, one pilot expands full coordinates of the point in the FMC (for the fourth time), and the NEXT and NEXT +1 waypoints. The PF reads from the CDU and the PM looks at the OFP with the circled and hashed waypoints. • PF reads from the FMS screen, PM re-verifies from flight plan. • Ensure that autopilot is in LNAV mode as each waypoint is crossed. • Check that the airplane is staying on the magenta line. • Also use tools in EFB to monitor route in flight. EFB route is an independent check on the FMS route. • The EFB has all the information you need for the FIR. • Usually set the ND range to show the next waypoint, but not required.
Cargo	• In-flight monitoring with the EFB moving map display. Pilots track the EFB display (Jeppesen FliteDeck Pro) to confirm the route, matches the OFP in the FMS • Verify: track, fuel and time of arrival. • Zoom into scale to make sure aircraft is on route. • Do not use paper plotting charts. • No preferred scale for ND; one option is to display the next waypoint.

	In-flight Route Monitoring
Passenger	• All of the route verification is done on the LEGS page of the CDU. • Check that the aircraft position is correct on the ND, per FAA AC 91-170B. We use the non-plotting method. • When approaching a waypoint, both pilots check the NEXT and the NEXT +1 waypoint for the current position in the LEGS page with the flight plan. They also check the course and distance. • Use ND to monitor, but this is based on pilot technique. There is no SOP. • Scale of ND is set based on use, e.g., to check weather or traffic, not for route monitoring. Might show a shorter range, e.g., 80 NM, when close to the next waypoint. Might show traffic if doing a lateral offset route in NAT. • Fill out position report log using information from the CDU position report page. PM keeps a log on an ARINC form.
Corporate	• PM plots route on a paper oceanic plotting chart as each waypoint is crossed. Verify it is the correct waypoint in the FMS and the position from the FMS (and other systems, e.g., GPS or IRS). • Plot another position check 10 minutes after crossing the waypoint. Check heading against flight plan too. Should be within 5° of planned heading. • Cross a waypoint every 60 to 90 minutes. • PM monitors overall navigation, chart plotting and communication. PF controls aircraft and monitors traffic on the ND. • ND is very useful. Personal preference. For example, PF has the map zoomed to next waypoint, course up. Zoom in as the waypoint comes closer. Also looks for traffic (e.g., monitor descending through traffic). PM has the ND in North-up view around 150 NM scale, to match the plotting chart.

Passenger	• Currently score (i.e., annotate or mark) a paper OFP.
	• Score the OFP. First check the position in the FMC, confirm in LNAV/VNAV mode, go to small scale on ND, check if on the magenta line, put in expected time. Same procedures as other US passenger airlines.
	• (Not asked to expand NEXT and NEXT+1 as they cross a waypoint.)
	• No SOP on how to split time between CDU and ND for flight path monitoring, but specific tasks must be accomplished:
	    ○ Score the flight plan
	    ○ Monitor the reporting time
	    ○ Monitor that the magenta line is on track
	    ○ Verify the inertial reference unit and GPS
	• ND is mostly in the longest ranges (320 or 640 NM), but when you cross a waypoint, zoom into 2 or 5 NM scale.

Comments on Waypoint Names

	Comments on Waypoint Names
Passenger	• Likes the ARINC 424 Paragraph 7.2.5 naming convention because of the geographic awareness it provides, even though the review steps (for expanding the waypoint coordinates) in the FMC are time consuming. • Sees no benefit in switching to named 5-letter waypoint labels because "if you can miss a number you can miss a letter."
Passenger	• In oceanic airspace there are too many waypoints to name, and naming all of them would not help pilots. • Support naming some waypoints but not others. • Pilots are trained to understand all conventions, and receive training on waypoint label ambiguity, but the ARINC 424 Paragraph 7.2.5 convention is especially confusing west of 100° longitudes. • Currently there are too many name formats to learn, and too many inconsistencies with the naming conventions in the computers and flight documentation. • West of 100° longitude, the ARINC 424 Paragraph 7.2.5 format is hard to understand (with N in the middle for whole degrees and one left of middle position for half-degree waypoints). This is where named waypoints would be beneficial. • Lateral deviation rate went up at the beginning of RLatSM trials. Before that, pilots did not pay attention to the position of the N in the waypoint name. • The EFB plotting chart does not show names for the half-degree waypoints.
Passenger	• CPDLC uplink comes from ATC using full latitude and longitude, regardless of naming convention in aircraft. ATC cannot send them any other way.
Cargo	• Naming oceanic waypoints depends on the amount of surveillance coverage of the ocean, and the frequency at which waypoints would be changed. • Currently with separate oceanic clearance it is better to have coordinates. • With full satellite coverage it would be better to have named waypoints, if the waypoints were fixed and the FMS database had sufficient capacity.

	Comments on Waypoint Names
Passenger	• There are a lot of waypoints to name. Some older FMSs are short on memory to hold all the new NAT waypoints. • Names are supposed to be pronounceable (i.e., exclude numbers), but numbers tell ANSPs the approximate latitude/longitude (which is useful). • Would need ANSP buy-in to change the waypoint names. They would need to have the names in their systems and train their staff. • On flight deck side, would have to update FMS database and train pilots. • If pilot makes a 1 digit mistake, it is not so obvious with the unnamed waypoints. • It takes more steps on the CDU to expand the coordinates of Hxxyy fomat waypoints, so they are not as visible. This is still a necessary step to be sure you are using the correct half-degree waypoint. • The ATC clearance never uses the Hxxyy format, so pilot has to translate it. This is an extra step.
Corporate	• No experience with FMS truncating or rounding waypoints. (General aviation equipment creates alternative names, such as a WPT01.)
Passenger	• Biggest issue with naming is the capacity of the FMS database. Boeing 777 is at 98% full now, even after removing some airports. Definitely not in favor of naming waypoints. • Every waypoint must be expanded prior to every flight and when you get oceanic clearance (twice). • Support naming waypoints when there is SB ADS-B reduced separation, but the waypoints would need to be named worldwide and we first need to understand the database size required for such a project. (Currently the FMS database is full.) • With SB ADS-B, will be more like over land operations, and special names for oceanic waypoints may be less important. But this will not work if the company is not equipped. • Compared to NRS waypoints, the unnamed (latitude/longitude) waypoints provide more geographic awareness. • NRS waypoints also introduce “fat-fingering” errors, such as transpositions, and they do not provide geographic awareness.

Other Comments

	Other Comments
Passenger	• Most deviations are vertical, not lateral. Conditional clearances are a problem. • Some lateral deviations are due to revised clearances. • Some pilots are still learning CPDLC, because they might have come from a different aircraft type (E-190) directly to oceanic operations and the B-787. A lot to learn. • It is time consuming to expand the waypoint coordinates. Sometimes this does not happen because of other tasks and distractions from ground personnel pre-flight. • There are some concerns that there may be more deviations with half-degree waypoints. • Errors can occur due to training quality and/or lack of discipline. Training on CPDLC is seen as lower priority than, say, VNAV approaches, which take up more of the training time. • Though the airline spends a lot of time on training in the classroom, the quality of the training could be improved.
Passenger	• There are a lot of distractions pre-flight (e.g., other people in the flight deck, company communications, ground crew). To manage workload, pilots may skip on the quality of the pre-flight route review. Pilots may not expand the waypoint coordinates pre-flight because most of the time the coordinates are correct and the process appears unnecessary. Needs self-discipline. Not a good job for a human. • It appears that "complacency" during route verification leads to the misinterpretation of waypoints by pilots who fly oceanic routes regularly. Pilots who fly few oceanic operations may prepare a lot more. • Younger pilots seem to trust the automated systems more. Older pilots did more crosschecks. • There is no instantaneous alert when the aircraft is off-course in the air, the only way to determine is to wait and plot the aircraft position to create the visually detectable difference on the charts. • Training is mostly verbal and hands-on in the simulator. Do train the naming conventions for the waypoints in the classroom and with bulletins. • More operators on random routes do not have CPDLC. Without CPDLC, do not have ADS-C conformance alerts or the "confirm assigned route" (UM137) messages, which can catch route errors.

	Other Comments
Passenger	• In total, each waypoint's coordinates are expanded *multiple* times. • Expand coordinates for all waypoints, regardless of whole or half-degrees. All airlines should do this. • No difference between how OTS and random routes are reviewed, either pre-flight or in flight. • Waypoints are expanded according to *NAT OPS Bulletin: RLatSM Special Emphasis Items—Phase 2 Update.* (2015-003 Revision 5) which has since been replaced by *NAT OPS Bulletin: Waypoint Insertion/Verification Special Emphasis Items.* (2018_003). They are expanded preflight (by both pilots individually), upon receipt of oceanic clearance, and again when approaching the oceanic waypoint. • If waypoint is in the Navigation Database, it should be correct, but there is an error potential. Still, pilots don't check these over the land. Same pilot may not check in oceanic, but oceanic flights are not full surveillance airspace, so it's a mistake not to check. • The printed OFP is likely to go away with future technology.
Cargo	• Robust SMS program; non-punitive. Pilots self-report. • Easy to make mistakes when entering coordinates. (If there are 10 people, someone will get it wrong.) It is rare that you need to – but that is why there is dual verification. • Pilots are more alert on oceanic routes because they are less frequent (x1 week), and pilots may only do one scheduled flight each year.

	Other Comments
Passenger	• On some route revisions from Shanwick, will see a “Memo” line, which has multiple pieces of information (e.g., change in flight level and a lateral route amendment). Critical information can be ignored if it is at the end of the memo line. • Gander gives a verbal reminder of a revised route clearance, which is helpful. • At Santa Maria, may need to call for route via voice. Accented English has been known to cause miscommunication of waypoint coordinates. • A 10 NM lateral deviation can happen quickly. The old definition of a GNE (25 NM) gave pilots some time to catch. • On random routes, revised clearance can be close to the original. Might just change one waypoint. “Insidious.” • Easy to confuse ACARs and CPDLC because the messages come up on the same screen in the flight deck. Some pilots use ACARS as the generic term for that screen. • Some pilots know that a change to the oceanic entry point means that the track changed. Some don’t. (Related to previous airline merger.)

Corporate	• Revised routes (reroutes) are a source of error, especially with CPDLC.
	• Another source of route errors is checking the flight plan waypoints.
	• CPDLC is new and still confusing for pilots.
	  • The message set is not user-friendly for pilots. Unusual things take time to figure out. We have a searchable PDF version of the manual on the iPad, but it is a “race against time in flight.” Would be great to have a checklist version as an in-flight reference.
	  • Another problem is that with CPDLC, pilots focus on the first thing they see, then forget about the rest. Especially true with high workload. And with random routes, can change any part. (With track route, usually the entire track changes.)
	  • Not all CPDLC route clearances are loadable. Depends on the control facility and region.
	• Avionics had some problems with DCL in the US. FMS was slow to process.
	• Training is through a third party, but also go to direct ICAO documents and other pilot websites (e.g., http://www.code7700.com)

Passenger	• There are more routing changes on random routes, and a route change introduces more error than any on track procedure.
	• Track routes take away airspace from more flexible routes.
	• Route changes add complexity for verification.
	• Pilots are trained on the ARINC 424 Paragraph 7.2.5 waypoint naming convention. Initially online.
	• Three types of lateral deviations, typically because the crew did not use the guide (one-page hard card).
	  o Crew went direct to the wrong waypoint
	  o Crew missed an intermediate waypoint
	• Crew did not get the Canadian route from the oceanic exit point, which Shanwick does not provide. This route is published and available in JeppView FliteDeck Pro. Not as common as they used to be.

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