Flight Deck Human Factors Issues Related to Instrument Flight Procedures (IFPs) at High Density Airports (HDAs)

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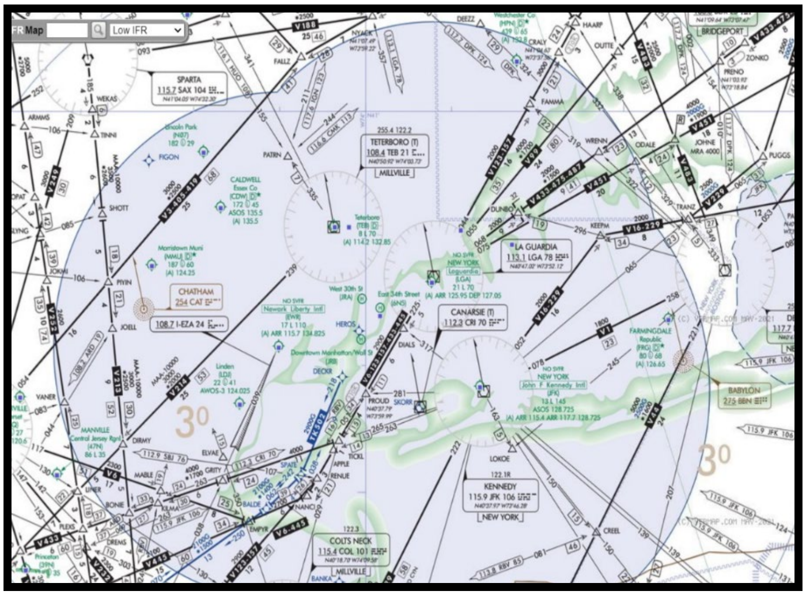
U.S. Department of Transportation



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13. ABSTRACT

This project addressed multiple research needs related to flight deck human factors perspectives on an emerging Next Generation Air Transportation System (NextGen) concept known as Multiple Airport Route Separation (MARS). MARS is an Air Traffic Control (ATC) concept that relies upon the development of pairs of instrument flight procedures (IFPs) to deconflict flights into and out of locations with multiple high-density airports. We performed several research tasks: (a) a literature review, (b) exploration of the concept of airspace complexity for pilots, (c) collection and analysis of data about flight operations in the New York metropolitan region as a case study, (d) assessment of one proposed application of MARS for New York, and (e) exploration of pilot resilient behaviors. We developed several recommendations for MARS from these activities. MARS applications should consider site-specific conditions related to traffic mix, weather, and pre-existing IFPs that are challenging. Assessments of the proposed IFP geometries should include a conceptual flythrough, applying results from previous research on subjective complexity of IFPs to identify potential issues from the pilot's perspective. Additional recommendations for MARS on topics such as pilot education, flight-deck equipment issues, and communications about MARS with ATC may be forthcoming from a government-industry working group.

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Performance Based Navigation; PBN; Multiple Airport Route Separation; MARS; Operational Complexity; Subjective Complexity; Airspace Complexity for Pilots; Resilience; Pilot Resilient Behaviors; New York

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yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
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yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
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yd^3	cubic yards	0.765	cubic meters	m^3
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		MASS		
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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**
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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		
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m^3	cubic meters	1.307	cubic yards	yd^3
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kg	kilograms	2.202	pounds	lb
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g	grams	0.035	ounces	oz
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		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

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List of Abbreviations

Abbreviation	Term
AAC	Arrival-to-Approach Connections
ACN	Accession number
AR	Authorization Required
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATIS	Automatic Terminal Information Service
CDTI	Cockpit Display of Traffic Information
CFR	Code of Federal Regulations
CPDLC	Controller-Pilot Data Link Communications
CRM	Crew Resource Management
EFB	Electronic Flight Bag
EoR	Established on RNP
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FMS	Flight Management System
FPM	Flight Path Management
GA	General Aviation
GPS	Global Positioning System
HDA	High-density Airport
HITL	Human-in-the-loop
IAF	Initial Approach Fix
IF	Intermediate Fix
IFP	Instrument Flight Procedure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
KBWI	Baltimore/Washington International Thurgood Marshall Airport, Baltimore, Maryland
KCDW	Essex County Airport, Caldwell, New Jersey
KDEN	Denver International Airport, Denver, Colorado
KEWR	Newark Liberty International Airport, Newark, New Jersey
KIAH	George Bush Intercontinental Airport, Houston, Texas

Abbreviation	Term
KJFK	John F. Kennedy International Airport, New York, New York
KLGA	LaGuardia Airport, New York, New York
KSEA	Seattle-Tacoma International Airport, Seattle, Washington
KTEB	Teterboro Airport, Teterboro, New Jersey
MCP	Mode Control Panel
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
PARC	Performance-Based Operations Aviation Rulemaking Committee
PBN	Performance Based Navigation
PF	Pilot Flying
PRM	Precision Runway Monitor
RA	Resolution Advisory
RF	Radius-to-fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RWY	Runway
SID	Standard Instrument Departure
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
TA	Traffic Advisory
TCAS	Traffic Alert and Collision Avoidance System
TF	Track-to-fix
TRACON	Terminal Radar Approach Control
VFR	Visual Flight Rules
VMC	Visual Meteorological Conditions

Preface

This document was prepared for the FAA NextGen Human Factors Division (ANG-C1), the Office of Aviation Safety (AVS), and the Flight Technologies and Procedures Division (Flight Operations Group, AFS-410 Section B). The FAA's Technology Development and Prototyping Division (ANG-C5) is also a stakeholder for the research described in this document.

This research is funded under the Fiscal Year (FY) 2019 Research, Engineering, and Development – NextGen Air/Ground Integration Project Level Agreement (PLA), Task 4. This document satisfies the PLA deliverable for Task 3, "Final Technical Report (04.03.00) describing research results, including generalizable recommendations to help reduce flight deck human factors impacts through the refinement of notional airspace geometries and IFPs at applicable sites." This document was prepared under the FF01C120 Interagency Agreement, "NextGen National Airspace System (NAS) and Flight Crew Procedures," tasks TJ494, TJ495, TK128, UJ495, VJ495, and UK128.

Thank you to Andrew Kendra and Dr. Janeen Kochan (Volpe Center) for their help analyzing the Aviation Safety Reporting System (ASRS) events and contributing to the work on flightcrew resilience.

The Volpe Center also thanks the FAA technical sponsors, Dr. Kathy Abbott (AFS) and Jeff Kerr (AFS-410), and the program manager, Dr. Victor Quach (ANG-C1), who was supported by Eddie Austrian (Fort Hill Group). We also thank stakeholders Mitchell Bernstein (ANG-C5) and Ted Goodlin (Contractor, ANG-C5). Thanks to Dr. Becky Hooey and her team from NASA's ASRS program for their assistance with gathering the reports analyzed in the study. Thanks to Cody Nichols and Jason Walls (AFS-430), who are conducting the Multiple Airport Route Separation (MARS) safety analyses, for sharing their knowledge. We also thank Dr. Jon Holbrook (NASA Langley), Jolene Feldman (San Jose State University Research Foundation), and Dr. Immanuel Barshi (NASA Ames) for sharing their insights about flightcrew resilience.

Executive Summary

This project addressed multiple FAA research needs related to flight deck human factors perspectives on an emerging Next Generation Air Transportation System (NextGen) concept known as Multiple Airport Route Separation (MARS). MARS is an Air Traffic Control (ATC) concept that would allow two aircraft to fly under reduced separation standards when both are flying along specially designed pairs of instrument flight procedures (IFPs) in airspace with multiple high-density airports (HDAs). The MARS IFP combinations, known as MARS "applications," would be designed to deconflict aircraft flying into or out of different airports in areas such as the New York (NY) metropolitan region. The IFPs that support MARS will be designed for aircraft flying with Global Positioning System (GPS) systems, ensuring that they meet navigation standards associated with Performance Based Navigation (PBN). This project examined the MARS concept from the pilot's perspective.

Tasks and Activities

This project was composed of several research tasks. The first was a literature review of concepts related to MARS, including PBN and a related concept called "Established on Required Navigation Performance" (EoR). The second task was to define and explore the construct of "airspace complexity for pilots." The third task was to collect and analyze data to understand flight operations in the NY region, which is a candidate for MARS. The fourth task was to assess one proposed MARS application for the NY region from a pilot's perspective. The last formal task was to make recommendations for the development of MARS. We added one other task to this list at the FAA's request, to explore pilot resilient behaviors as part of our data analysis.

We accomplished these research tasks through a combination of conceptual work, data analysis, and data collection. Using the literature review as a starting point, we created a working definition of the construct of airspace complexity for pilots. We used this definition to identify related events from the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS), to study pre-COVID NY flight operations. We then analyzed these ASRS events using a structured coding rubric to understand current operational issues at NY. We also studied resilient pilot behaviors through the NY ASRS dataset.

To supplement our knowledge of NY flight operations, we gathered subjective data through listening sessions with a diverse sample of pilots who fly in the NY area regularly. The sample included pilots from business aviation, major airlines, and a regional airline. We gained a deeper understanding of ATC interactions with pilots and pilot awareness of traffic in the NY area through these sessions. We also solicited input from pilots on the general idea of the MARS concept in the sessions.

We gathered input on PBN and MARS from subject-matter experts, including airline pilots and ATC representatives, through the Pilot-Controller Procedures Systems Integration (PCPSI) government-industry working group. Our work with PCPSI, and its subgroup on Approach-Arrival Connections, in combination with our prior work regarding line-pilot perspectives of IFP complexity, helped us to develop a method for a conceptual evaluation of a MARS application.

We developed recommendations for the development of MARS through a synthesis of our conceptual and data-driven research. We shared these recommendations with other researchers and industry throughout each stage of this project.

Key Findings and Recommendations

Our key findings are grouped into three categories. First, we made progress related to the concepts of airspace complexity for pilots and resilient pilot behaviors. Our definition of airspace complexity for pilots is composed of four types of external threats: ATC interactions, flight deck equipment, airspace, and environment. We use “threat” the same way that it is used in the threat and error management model of flight deck operations. In terms of analyzing resilient pilot behaviors, we found that ASRS events offer an incomplete picture. Research teams need to decide how to operationalize the concept of resilient pilot behaviors; these decisions will vary based on the purpose and assumptions of the project. Our concept of resilient pilot behaviors was developed to identify examples of adaptive expertise. It was best operationalized by a model proposed by Dekker and Lundström (2007).

Our findings about NY came from both the ASRS event analysis and the pilot listening sessions. ATC interactions were involved in 67% of the ASRS events in our dataset (49 out of 73). We also found that IFPs with complex features, such as altitude and speed constraints, were rarely identified in the NY ASRS data. These IFP design-related events were more prevalent in data from a prior study (Chandra, Sparko, Kendra, & Kochan, 2020), which studied ASRS events from locations with PBN. The listening sessions confirmed much of what we learned about NY through the ASRS events. We also learned more detail about the mix of traffic, local techniques, and knowledge (i.e., “unwritten rules”), ATC expectations and style. NY is a unique (nonstandard) airspace in some ways, but operations are still predictable for pilots with local flight experience. Also, NY has additional areas for improvement besides just PBN (e.g., better communication of unwritten rules, improved departure sequencing and transparency about departure routes).

Our research produced several recommendations for the development of MARS, both at NY and in general. First, there are site-specific considerations, such as understanding the local mix of traffic, the local weather, and pre-existing local IFPs that are challenging. MARS should also consider the airspace complexity profile of each site. MARS applications also need to consider operational complexity. Recommendations on these subjects may be forthcoming from the PCPSI Approach-Arrival Connections subgroup. The working group’s recommendations may address the need for pilot education, communications between ATC and pilots about approach-arrival, and flight deck equipment issues related to automated systems used to fly approach-arrival connections. We also recommend that MARS applications be refined by doing a conceptual flythrough of the IFPs from a pilot’s perspective, as we have done for one example application. This assessment technique makes use of the findings from an earlier study on the complexity of IFP designs from a line-pilot perspective (Chandra & Markunas, 2017).

Key Takeaways

The MARS concept has the potential to achieve multiple goals at locations such as NY. It would encourage the development and use of PBN IFPs, which could increase the safety and efficiency of flight operations. However, NY is a challenging area for PBN IFPs. The transition to PBN will need to be coordinated carefully, ideally in a way such that benefits are noticed by all users at each stage of implementation.

1. Introduction

The FAA requires research to identify and address flight deck human factors issues related to emerging Next Generation Air Transportation System (NextGen) concepts. This project considers the potential flightcrew-task impacts of Performance Based Navigation (PBN) and Multiple Airport Route Separation (MARS), a NextGen concept that utilizes PBN elements. PBN is an enabling technology for NextGen that relies upon Area Navigation (RNAV) and Required Navigation Performance (RNP). PBN describes an aircraft's ability to navigate in terms of performance standards using RNAV and RNP (FAA, 2016). RNAV capability can be achieved within the coverage of ground- or space-based navigation aids, per the aircraft equipment capabilities. RNP is RNAV with the addition of onboard performance monitoring and alerting capability.

The Volpe Center has conducted research on the complexity of flight deck operations for PBN instrument flight procedures (IFPs) since 2009. We identified different types of complexity related to the design of the IFP, the charting of the IFP design, and operational complexity factors (for pilots) that vary from day-to-day (Chandra & Markunas, 2017; Chandra et al., 2020). Operational complexity is associated with Air Traffic Control (ATC) interventions, aircraft automated systems (e.g., ease of use), crew factors (e.g., fatigue and familiarity with the airspace), operator factors (e.g., support for route planning), and environmental factors (e.g., traffic, weather, terrain, and airport runway configuration).

The goal of MARS is to develop new terminal IFPs based on PBN that would allow separation of air traffic through Monitored Procedural Separation (MPS) across multiple airports with high air-traffic densities in close proximity (FAA MARS ConOps v1, 2019).[1] New IFPs that support MARS could include Standard Terminal Arrival Routes (STARs), Standard Instrument Departures (SIDs), and Instrument Approach Procedures (IAPs) with RNAV segments. The FAA envisions using MARS at places such as Southern California, Dallas, and the New York metropolitan region.

The MARS MPS concept is an alternative to tactical radar separation. When the MARS IFPs are appropriately designed and paired, MPS could be used to procedurally separate traffic flying specific route segments on different terminal IFPs going to (or from) different airports. The separation between the aircraft may be less than standard tactical radar separation because the aircraft are "established"[2] on the different IFPs, traveling along paths that will diverge, whereupon tactical radar separation will be resumed.

Established on RNP (EoR) is a similar ATC operational concept that has been used within a single airport terminal for parallel runway landing operations.[3] EoR has been used at Seattle, Denver, and Houston (FAA EoR Guidelines, 2020; Thomas et al., 2018; Thomas & Serrato, 2019). EoR allows ATC to clear an aircraft for an RNAV (RNP) approach with reduced spacing (i.e., less than the minimum of 1000 ft vertical separation or 3 NM radar separation) from an aircraft established on an approach to a parallel runway. EoR provides shorter, repeatable, and stabilized paths to the runway for the aircraft on the RNAV (RNP) approach and it helps to increase the utilization of RNAV (RNP) approaches.

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[1] More specifically, IFPs that support MARS will be a subset of PBN IFPs because MARS *requires* the use of the Global Positioning System (GPS), whereas GPS is just one potential means of achieving PBN.

[2] The FAA Pilot/Controller Glossary (2021) defines "established" as being "stable or fixed at an altitude or on a course, route, route segment, heading, instrument approach or departure procedure, etc."

[3] As with MARS, EoR requires the use of GPS. EoR also requires pilots to use either an autopilot or hand-fly with a flight director.

Although current EoR applications utilize RNAV (RNP) approach procedures with Authorization Required (AR),[4] EoR is approved for use with all vertically guided approaches, including Instrument Landing System (ILS) approaches (Thomas et al., 2018). MARS is a generalization of EoR in that it applies to all types of terminal IFPs, not just approaches; MPS might be applied to any combination of arrival, departure, or approach IFPs, or even to a missed approach procedure segment. Also, MARS is applied to combinations of flight paths for different airports, whereas EoR is only applicable to two runways at the same airport.

The MARS Concept of Operations (ConOps) Version 1 (FAA MARS ConOps v1, 2019) proposes combinations of IFPs for hypothetical MARS "applications." According to this concept, MARS will:

> …support Arrival/Departure at High Density Airports (HDA) by eliminating conflicting IFPs between airports at some of the Nation's busiest terminal areas. It is considered an operational improvement under the title of 108215 – 'Increase Capacity and Efficiency Using Streamlined PBN Services' (FAA MARS ConOps v1, 2019, p. 7).

Although MARS is primarily an ATC-operations concept, it may have implications for flightcrew tasks and workload. Therefore, the goals of this project are to (1) anticipate how the design of IFPs for different MARS applications could impact flight deck tasks and (2) propose recommendations on how to mitigate any potential negative impacts. The recommendations might apply to all PBN IFPs, not just those used for MARS.

MARS is a nationwide concept, but we focus on the New York (NY) area as a case study. NY is one of the regions mentioned in the MARS ConOps (2019). The FAA and industry are interested in improving the efficiency of operations in the NY terminal airspace (FAA NextGen Priorities, 2020). In 2018, under the NextGen Advisory Committee (NAC), the Northeast Corridor (NEC) NextGen Integration Working Group (NIWG) developed recommendations for NY that led to the proposed FAA MARS applications for NY (NAC, 2018).

The FAA will select test sites for MARS after conducting a series of MARS safety analyses, which will be conducted over the next few years. The safety analyses for MARS will also determine whether autopilot, or hand-flying with a flight director, will be required for MARS (as they are for EoR). These studies, which include Human-in-the-Loop (HITL) simulations, are similar to the ones conducted for EoR (Walls et al., 2016, 2017a, 2017b). The MARS test sites have not been selected as of the date of this report.

The FAA is the primary audience for this report. Other audiences may include parties interested in NY airport operations, PBN IFP designers, and researchers studying flight deck human factors issues (e.g., flightcrew resilience).

Section 2 of this report provides an overview of the project. Section 3 describes literature related to PBN operations, EoR, and airspace complexity. Section 4 presents our data collection and analysis of current flight operations at NY. Section 5 addresses resilient flightcrew behaviors, which we studied as an addendum to our analysis of NY operations. Section 6 discusses the MARS concept. It includes an introduction to IFP design and has a preliminary examination of one notional MARS application. Section 7 focuses on the connection between STARs and IAPs with an emphasis on PBN IFPs and the impacts of operational complexity. This section summarizes work being done by a government-industry group that is developing recommendations for arrival-approach connections. Section 8 contains our recommendations for MARS. Section 9 contains a summary and conclusions of this research.

[4] See FAA Advisory Circular 90-101A, 2011. RNAV (RNP) is the chart naming convention for RNP (AR) procedures. For example, "RNAV (RNP) RWY 23" is the title of an RNP (AR) approach procedure to runway (RWY) 23.

2. Project Overview

The FAA asked the Volpe Center to identify and address potential flight deck human factors impacts related to the MARS concept. The Volpe Center accepted five tasks:

- Conduct a literature review of related concepts (e.g., PBN and EoR)
- Explore airspace complexity for pilots
- Collect and analyze data to better understand issues pilots face currently, at a location where MARS might be used. The FAA asked us to study the NY region.
- Review at least one notional MARS application
- Make recommendations for MARS

This project and its data collection efforts are structured around three overlapping research threads that apply to the MARS concept: PBN terminal IFPs, HDAs, and the NY metropolitan region (see Figure 1). MARS is intended for areas with airports that have high air-traffic densities and are in close proximity. It relies upon the use of PBN IFPs (and GPS). The NY region is a potential candidate for MARS with its multiple HDAs, but it has been slow to adopt PBN. We explored what currently makes NY challenging from a pilot's perspective.

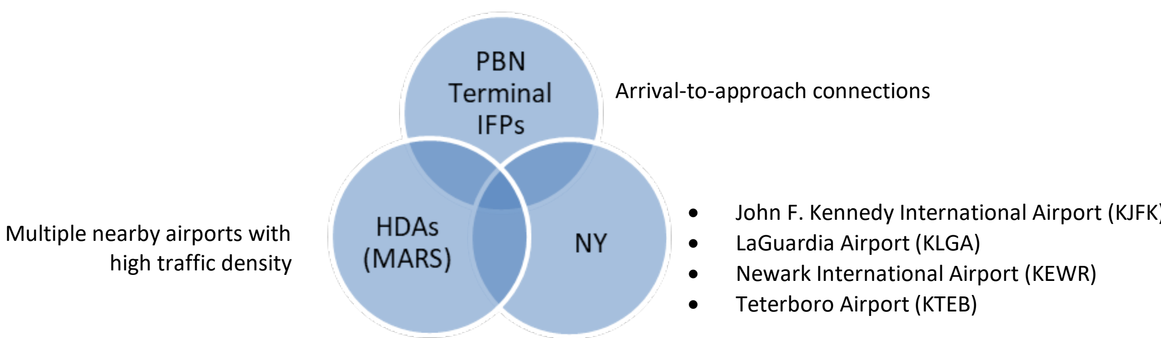


Figure 1. Overlapping research threads.

For the PBN IFP thread, we focus on the connection from an arrival to an approach. More specifically, this connection is between the termination point of a conventional or RNAV arrival to a fix on the published instrument approach. An aircraft on a STAR can join an approach via ATC vectors or a published runway (approach) transition. The type of connection will vary based on the type of approach to be joined (e.g., ILS versus or visual approach) and the ATC operations in progress (e.g., the runway configuration in use). The aircraft could join at various waypoints along the published runway (approach) transition, from the initial approach fix (IAF) to the intermediate fix (IF). Flight paths that connect arrivals and approaches can be an area of risk because this is a time-sensitive portion of the flight. Pilots might get a route amendment at the last moment, and that might lead them to fly a path that was not cleared by ATC or to become confused and uncertain about what path to fly.

Figure 2 illustrates the project structure. It shows the three main research threads from Figure 1 along with two others: airspace complexity and resilient pilot behavior. The FAA formally tasked us with exploring airspace complexity for pilots. We developed a concept of airspace complexity that captures the kinds of external threats pilots might experience at an HDA. The FAA is also interested in flightcrew resilience and how pilots contribute to safety during flight operations, so we agreed to explore resilience as a side effort.

The figure maps each research thread to one or more activities. The activities are:

1. Analysis of events from National Aeronautics and Space Administration (NASA)'s Aviation Safety Reporting System (ASRS), including a custom set of reports from NY as well as a subset of PBN-related events from a previous study (Chandra et al., 2020) that occurred on arrival-to-approach connections at various locations nationwide. We used our concept of airspace complexity to inform this analysis.
2. Gathering input from line pilots who regularly operate in the NY region to learn about current flight operations.
3. Participation in a government-industry working group tasked with addressing issues related to arrival-to-approach connections for PBN IFPs. The Arrival-to-Approach Connections subgroup is part of the Pilot-Controller Procedures Systems Integration (PCPSI) working group which operates under the Performance Based Operations Aviation Rulemaking Committee (PARC).

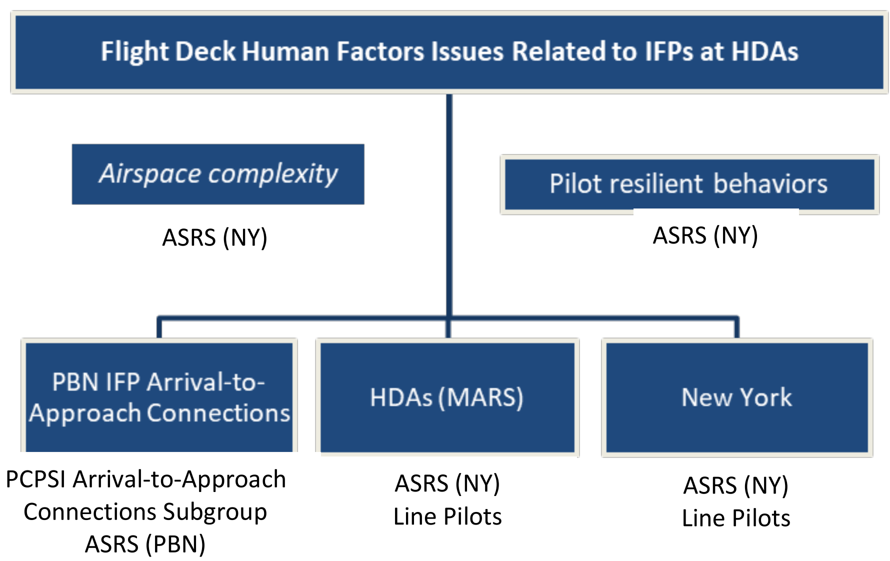


Figure 2. Project structure and activities.

3. Literature Review

In this section, we review three types of related studies. Section 3.1 addresses the complexity of flight deck operations for PBN. Section 3.2 reviews studies of EoR. Section 3.3 considers what is known about airspace complexity.

3.1 Pilot Perspectives on the Complexity of PBN Operations

PBN increases the safety and efficiency of flight routes by using RNAV and RNP. When aircraft are established on PBN IFPs, it gives ATC confidence in their current and future trajectory. However, PBN also introduces challenges for flightcrew performance such as new (additional) types of IFPs, increased numbers of waypoints and flight path constraints to review, more branches on the IFPs, and more notes and information on aeronautical charts. These challenges may cause pilots to rely more on their automated systems, which could in turn lead to difficulties if the automated systems do not function as expected. These challenges can also make the decision to accept or reject a PBN IFP more complicated because the pilot must comprehend and evaluate a lot of data about the proposed route.

The Volpe Center has over a decade of experience examining PBN IFP complexity from the pilot's perspective. Two studies in particular form the basis for our current research. The first (Chandra & Markunas, 2017) studied "subjective complexity," which was defined as *anything that creates extra mental or physical steps for the flightcrew*. Subjective complexity factors are a source of difficulty for pilots when flying or reviewing IFPs because they create additional tasks to manage and prioritize. Chandra and Markunas (2017) observed flightcrews as they reviewed and briefed IFPs using the charts and asked structured follow-up questions. They identified three main categories of subjective complexity factors:

- *IFP Design Issues.* This category is the main driver of subjective complexity. It includes factors such as energy profiles, constraints, the number of IFP transitions (i.e., branches), and waypoint names, for example.
- *IFP-induced Chart Issues.* This category is the second source of subjective complexity. It includes factors such as visually noncontiguous paths (e.g., long paths spread across two pages) and constraints; more constraints result in more visual complexity on the chart.
- *Chart-specific Issues.* This category is the smallest source of subjective complexity. It includes factors such as the arrangement of the data, nonstandard notes, etc., which may be independent of the IFP design.

Chandra and Markunas (2017) also point out two crosscutting issues that go beyond IFP and chart design—visual density and inconsistencies between different types of IFPs. Dense airspaces (with high traffic and/or many routes) often require complex IFP designs with many waypoints and flight paths, which increase the visual density of the chart. Pilots also noted inconsistencies between how speed and altitude constraints were depicted on IAPs versus SIDs and STARs. Updated charting conventions have since resolved some of these discrepancies.

Chandra and Markunas (2017) also called out factors that were beyond the control of IFP and chart designs. These *operational complexity* factors include ATC Interventions, Aircraft Equipment or Performance, Environment, Flightcrew Factors, and Operator Factors. Operational complexity factors emerge from day-to-day variations (e.g., traffic or weather) that flightcrews must manage. In a follow-on study, we analyzed ASRS events that occurred on PBN arrivals and approaches to expand our understanding of the operational complexity factors (Chandra et al., 2020).

Figure 3 shows examples of the factors we identified in each operational complexity category.

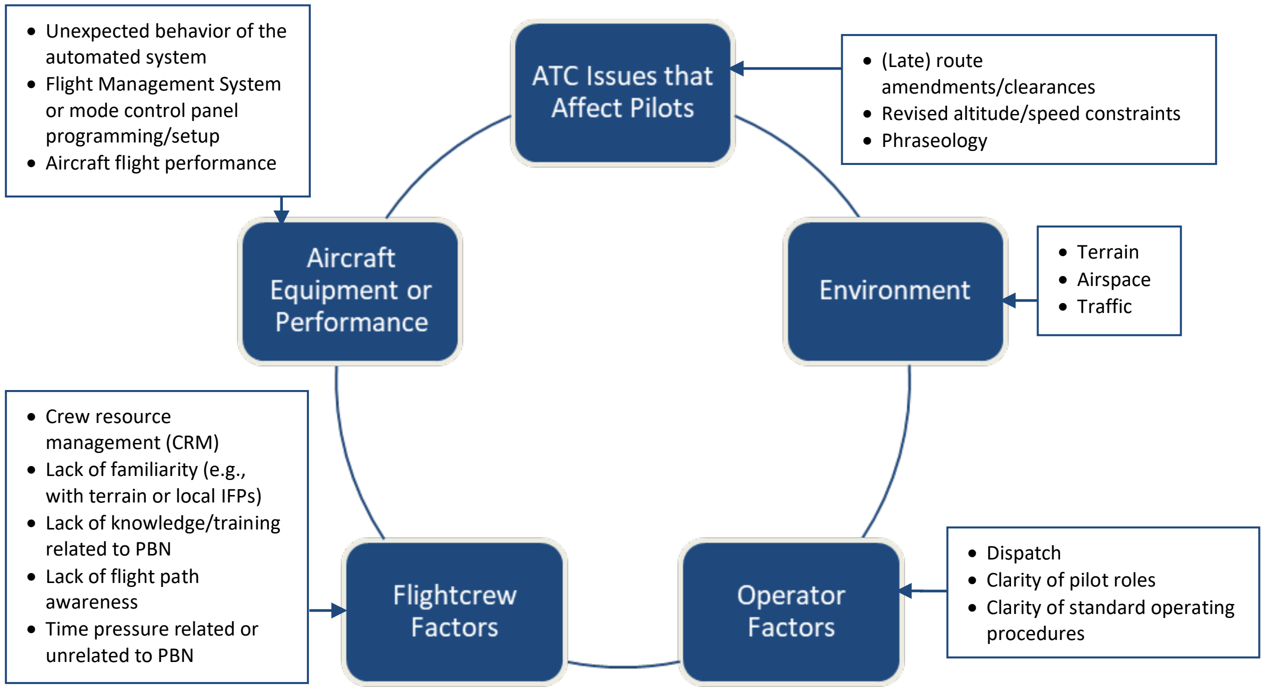


Figure 3. Operational complexity categories and example factors.

Figure 3 shows only a selection of the operational complexity factors we found. The full list of factors was partitioned by whether the factor was related to PBN or not. In a dataset of 164 ASRS reports, we found 148 events (90%) that were related to PBN (Chandra et al., 2020). The analysis identified many operational complexity factors that were related to PBN and many of these, in turn, were related to flight crew and ATC behaviors.

We concluded that PBN appears to magnify the effects of operational complexity in our dataset (Chandra et al., 2020). While experienced pilots may know how to deal with most types of operational complexity, PBN operations may require a deeper knowledge that can only be developed on the line. Weaknesses in pilot understanding can be revealed by PBN. Therefore, we recommended that the FAA, operators, and flightcrews work together to promote a culture of "adaptive expertise." Adaptive experts are those that can be flexible and apply their knowledge to novel or atypical situations (Hatano & Inagaki, 1986). Adaptive expertise has parallels to resilience, which we discuss in Section 5. Giving pilots the opportunity to practice PBN operations and experiment with methods and solutions may help to develop adaptive expertise and resilience. For example, RNAV (RNP) approaches could be conducted in visual conditions for practice. We saw this strategy in some of the ASRS events, and it was also used successfully to ease pilots into flying EoR approaches at Denver International Airport (KDEN).

3.2 EoR

FAA safety studies used a pilot HITL simulation to model airborne aircraft-to-aircraft collision risk during EoR operations (Walls et al., 2016; Walls et al., 2017a). Collision risk was remote under both nominal and off-nominal conditions, including flight guidance equipment failure and wind/turbulence scenarios that could lead to flight path deviations. Pilots generally felt that the experience of flying under EoR operations was similar to flying "typical" approaches, though their ratings of the off-nominal scenarios were slightly less favorable than their ratings of the nominal scenarios. The largest difference was for the scenarios with an equipment failure. None of the differences were statistically significant.

Some of the scenarios simulated a traffic conflict with an ATC-directed breakout while the subject aircraft was turning to final. The required flightcrew procedure for breakout maneuvers on simultaneous approaches to closely spaced parallel runways is to immediately disconnect the autopilot and hand fly (FAA Aeronautical Information Manual, AIM, 2021). However, some pilots in this study failed to disconnect the autopilot or did not disconnect it immediately. The difference in breakout performance seemed to be due to training; flightcrews who flew aircraft with vertical navigation (VNAV) reported that they did not practice breakout maneuvers often, whereas flightcrews who flew aircraft without VNAV said they are trained on the maneuver annually (Walls et al., 2016).

Walls et al. (2016, 2017a) also modeled the rate of nuisance Traffic Alert and Collision Avoidance System (TCAS) alerts under different EoR flight path configurations and altitudes. Nuisance alerts could reduce flightcrew comfort and lead them to deviate from their flight path, undermining EoR efficiency benefits and, potentially, safety. The risk of nuisance TCAS alerts was greatest when the two aircraft were on opposite facing base legs (i.e., when they were in a head-to-head configuration), but the risk was reduced by extending the leg that intercepts the final approach for the RNAV (RNP) approach. This ensures that the aircraft will be at a lower altitude when turning onto the final approach segment, where the TCAS sensitivity is less conservative as they begin to converge.

In a third study, Walls et al. (2017b) modeled the collision risk when an aircraft cleared for an EoR approach had the wrong IAP loaded. Pilots must select their approach in the Flight Management System (FMS) from a list of available IAPs which may have similar names. Pilots may be susceptible to selecting the wrong IAP under high workload or time pressure, such as when ATC makes a late change to the approach clearance. Walls et al. found that ATC intervention is critical to maintaining safety when pilots select the wrong approach during EoR operations. To be most effective, ATC needs at least 50 seconds between the time they realize the error and the time the aircraft would cross the path of another aircraft. The FAA incorporated this “50 second rule” into the IFP design criteria by requiring simultaneous PBN IAPs to diverge on a unique initial or intermediate approach track for at least 50 seconds prior to the point where one aircraft might converge on the other’s final approach course (FAA Joint Order 8260.3E, Section 15-5-3, 2020).

Thomas et al. (2018, 2019) conducted a two-phase project to identify and validate human factors guidelines for EoR implementation. In Phase 1, they visited Seattle-Tacoma International Airport (KSEA) and KDEN—two EoR “early adopters”—to interview controllers and pilots (Thomas et al., 2018). Their focus was on the ATC perspective, so the pilot data collection was supplementary and small; they spoke to just six technical pilots who were involved with the development of EoR at each facility. In Phase 2, they developed implementation guidance (based on what they learned at KSEA and KDEN) and validated the guidance at George Bush Intercontinental Airport (KIAH) through interviews with controllers (Thomas & Serrato, 2019). We highlight the findings that are relevant to flight deck human factors, IFP design, and PBN adoption, below.

- Pilots often do not have enough time to reprogram the FMS when ATC changes the clearance, especially when they change the from an RNAV (RNP) approach to an ILS. If ATC must take the flightcrew off the RNAV (RNP) approach, pilots find it easier to fly vectors than to program a different IAP.
- The time it takes to program the FMS varies by equipment, so there is no standard lead time that ATC should give pilots for clearance changes. Programming challenges are exacerbated when the STAR terminus does not connect smoothly with the first fix on the IAP (e.g., if the fixes have different altitude constraints).
- Unpublished speed restrictions are easier to manage when in level flight. Ideally, the connection between the STAR and the approach would have a level segment to give pilots more flexibility in

managing speeds. Controllers interviewed for this study expressed the need to use speed control to make EoR work when there is traffic compression or wind. They also acknowledged that different aircraft slow at different rates.

- At KIAH, controllers' confidence that the pilots would conform to the IAP was degraded when they perceived that flightcrews were "hand-flying" the approaches.[5] Thomas and Serrato (2019) could not verify whether pilots hand-flew the approaches. They hypothesized that the *appearance* of hand-flying on the radar display could result from pilots flying the IAP with the flight director rather than the autopilot (which are both are allowed for EoR), or pilots hand-flying without flight director (which is not allowed) as they tried to connect the arrival to the approach.
- Pilots were concerned about the risk of selecting the wrong IAP in the FMS, reflecting Walls et al. (2017b). Having a single path to each runway would give pilots and controllers more time to correct potential errors.
- Pilots noted inconsistencies in the terms used by ATC and pilots. For example, pilots referred to the approaches used for EoR as "RNP (AR)" while controllers referred to them with the approach suffix letter (e.g., "Zulu"). Pilots are not familiar with the term "EoR."
- At KSEA, pilots tended not to ask for the RNAV (RNP) approach procedure because they were used to getting an "unable" response from ATC. It is also harder to reprogram the FMS if ATC takes them off the RNAV (RNP) approach procedure. Controllers expressed hesitancy in issuing an RNAV (RNP) approach at KSEA. For example, two feeder controllers said they leave the decision to the final controller, who may have other plans. One controller did not like issuing RNAV (RNP) approaches for EoR because the controller has less control over them.
- Other influences on controllers' use of EoR approaches included: (a) the difficulty of sequencing mixed-equipage traffic for different types of approaches and (b) whether the controllers believed that the IAP design was better than what they could achieve with vectors. KDEN implemented EoR approaches that overlaid existing visual approaches, allowing controllers to visually compare the two approaches and see the benefits of EoR.

Thomas et al. (2018) concluded that successful EoR implementation is facilitated by a phased implementation and change management plan. The plan should be communicated and trained to controllers early on to gain acceptance. There are also ways to ease controllers and pilots into EoR operations. At KDEN, EoR was initially used on an overflow runway in Visual Meteorological Conditions (VMC), which helped controllers get familiar with EoR approaches under relatively low-risk conditions. RNAV (RNP) approaches for EoR might be designed to overlay or improve the efficiency of a conventional (e.g., visual or ILS) approach. All stakeholders should be involved in the IFP design to maximize usage. Operators may have different needs, so the best option may be to design IFPs that provide short-term benefits for all operators, regardless of equipage.

Many of the conclusions from Thomas et al. (2018, 2019) might apply to NY as it increases PBN usage, and for any HDAs as they transition to PBN and consider MARS applications. Not surprisingly, many of the flight deck human factors issues found in Thomas et al. (2018) reflect generic PBN issues that we found in our own work (e.g., Chandra & Markunas, 2017). One question about MARS that the EoR and PBN literature does not address is what pilots know about traffic at other nearby airports when they are operating at an HDA. We address this research gap with our current data collection (see Section 4.4).

[5] When flown as required by FAA standards, there should be no perceptible difference between hand-flown approaches with the flight director and approaches flown with an autopilot. It is not clear why controllers perceived that some flights were hand-flown in the Thomas & Serrato (2019) study.

3.3 Airspace Complexity

We explored the literature to inform our concept of terminal airspace complexity for pilots. We did not perform a comprehensive literature review. Here we give a brief overview of the papers we did review.

3.3.1 ATC Perspective

Airspace complexity has been studied extensively from the controller perspective. The research we reviewed describes airspace complexity for controllers in terms of parameters that predict controller workload. Sridhar et al. (1998) defined an objective and measurable parameter of airspace complexity called *dynamic density.* Dynamic density takes into account the number of aircraft as well as their relative positions and how those positions (and geometries) are changing over time. Other researchers have worked to refine the variables that could predict dynamic density and airspace complexity (and thus workload) for controllers (e.g., Kopardekar et al., 2007; Histon et al., 2002; Lee, 2008). They studied variables such as air traffic (amount, flow structure, climbing/descending/turning, proximity to each other, etc.); sector spatial and physical attributes (e.g., terrain, airways, navigation aids); and flow characteristics that vary over time and depend upon features such as number of aircraft, mix of aircraft, weather, separation between aircraft, and closing rates. Weather also impacts airspace complexity for controllers, but it is hard to measure. Kopardekar et al. (2007) used a stepwise linear regression to identify variables that predicted controller workload ratings for the Cleveland airspace. The variables came from four categories: monitoring-related variables (e.g., number of aircraft per occupied volume, number changing altitude), decision-making-related variables (e.g., time to conflict, angle of convergence), communications variables (e.g., proximity to sector boundary), and data entry/record keeping variables (e.g., number of speed/altitude changes).

One clear finding regarding airspace complexity for controllers is that it is time sensitive. It can vary across as little as 20 minutes, depending on traffic peaks and weather events, for example. In Sridhar et al. (1998), predictions of airspace complexity 5 minutes out were more accurate than predictions for the 20-minute timeframe. Airspace complexity also varies as a function of the specific airspace. Variables that predict airspace complexity for one location may be less predictive for another airspace (Kopardekar et al., 2007).

3.3.2 Pilot Perspective

Relatively little research has been done on airspace complexity from the pilot perspective. The research we found focuses on specific tasks that can be affected by airspace complexity. For example, Riley and others (Riley et al., 2003; Riley et al., 2004) studied airspace complexity for pilots in the context of self-separation through flight deck traffic displays, with and without conflict-resolution aide software. They showed pilots a Cockpit Display of Traffic Information (CDTI) and allowed pilots to view data about each aircraft on the display. After reviewing the scenario, pilots rated the complexity of the airspace. The pilot ratings were modeled with a neural network. Researchers identified 11 spatio-temporal traffic-related factors that appear to be most influential.

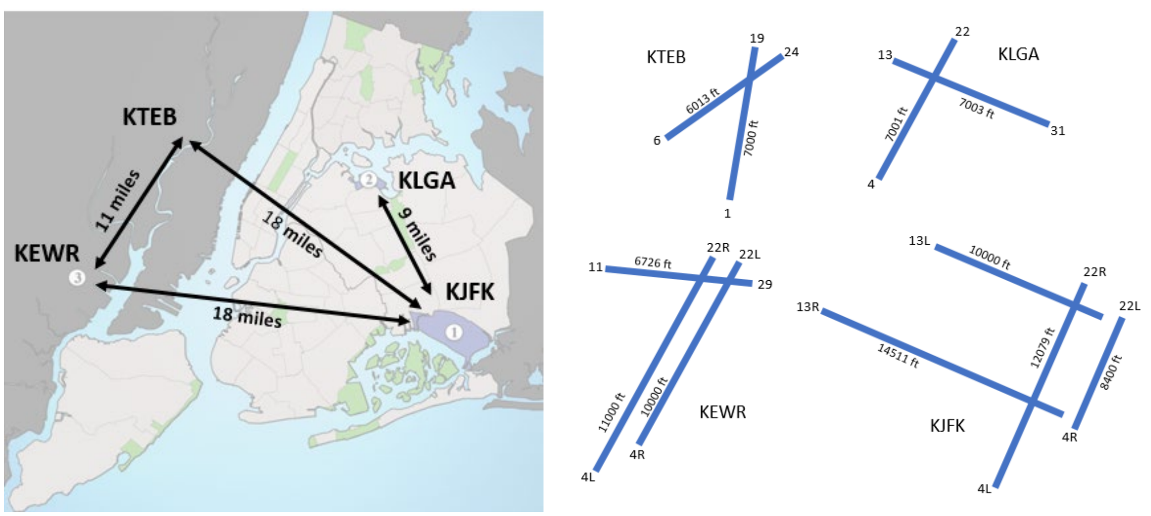
Riley et al. (2004) mention that the concept of airspace complexity is relevant to other pilot tasks, not just to flight-deck decision aids for conflict resolution. They recognized that the definition of airspace complexity should be expanded to include real-world aspects such as weather (and, especially, fast-moving weather), restricted airspace, terrain, and flight plans that change. They say it is necessary to study a more “dynamic and uncertain environment that is more analogous to the real world” (Riley et al., 2004, p. 3.A.5-11). They did not directly mention that airspace complexity is also time sensitive for pilots, but we expect that time would be a factor for pilots just as it is for controllers.

4. Current Operations at NY

This section documents our work to understand operations at NY prior to any impacts of COVID-19. Section 4.1 describes the physical locations of the four major airports, their runway configurations, and flight path conflicts. Section 4.2 describes how we operationalized our concept of airspace complexity for pilots, which consists of different external threats related to HDAs. We examined two sources of data about NY operations. First, we reviewed reports filed with the NASA ASRS. Second, we listened to pilots who currently fly either scheduled commercial flights or business aviation operations in the NY area. Our ASRS analysis is presented in Section 4.3. The pilot listening sessions are covered in Section 4.4.

4.1 NY Airports and Runway Configurations

NY has a complex terminal airspace in part because of the close physical proximity of its four major airports. All four airports are within 20 miles of each other; KJFK is 9 miles southeast of KLGA and 18 miles east of KTEB and KEWR (Figure 4a). Their relative locations and runway configurations (Figure 4b) constrain the arrival, departure, and approach procedures that can be assigned to aircraft while keeping them safely separated. In addition, their proximity necessitates coordinated changes to the airport runway-use configuration. Operations for all the core NY airports are controlled by a Terminal Radar Approach Control (TRACON) that is known for its fast-paced communications and strong expectations of pilot responsiveness to assigned headings, altitudes, and speeds, especially during VMC when arrival and departure rates peak. The NY region has been slow to adopt PBN. ATC typically issues pilots vectors to a visual or ILS approach. This means that pilots and ATC have constant and rapid communications.



a. Airport relative spacing* b. Runway configurations

*Image adapted from Julius Schorzman, CC BY-SA 2.5, https://commons.wikimedia.org/w/index.php?curid=280246

Figure 4. NY airport and runway configurations.

Conflicting flight paths for the NY airports typically cannot be resolved by radar vectoring or vertical separation. Often one airport must stop operations to/from the conflicting runway until conflicts with the other airport are clear. For example, IAPs to KTEB runway (RWY) 19 conflict with the IAPs to KLGA

RWY 13 because the flight paths cross. When air traffic is operating in a southwest flow, ATC cannot separate the traffic vertically because KEWR is landing RWY 22L above KTEB and KLGA operations.

Another factor that complicates operations at NY is the density of aircraft operations. In 2019, there were over 1.4 million flight operations at the four airports combined, and more than 1 million of these were air carrier operations.[6] For comparison, Atlanta (KATL) had just over 900,000 total flight operations in 2019. It is the combination of four busy airports near each other that makes NY a complicated and very busy airspace.

4.2 Airspace Complexity Threats for Pilots

We drew on the airspace complexity literature (Section 3.3) and our own research on subjective and operational complexity (Section 3.1) to develop a definition of airspace complexity for pilots operating at HDAs. We considered airspace complexity to be that which *arises from* *external* *threats to the flightcrew that are related to managing their flight path in the terminal airspace*. We use "threat" the same way that is used in the Threat and Error Management model of flight deck operations but we tailored it to the types of threats that pilots might experience at an HDA in the terminal environment.

We identified four categories of airspace complexity threats: *ATC Interactions, Flight Deck Equipment, Airspace*, and *Environment*. Essentially, we think of airspace complexity as a subset of operational complexity that excludes factors that come from the pilot or the operator (e.g., fatigue, training, or company standard operating procedures), except those introduced by programming or configuring aircraft equipment. Another key difference between our concept of airspace complexity and operational complexity is that we separated out individual sources of time-pressure (i.e., from ATC interventions or equipment setup) for the airspace complexity threats. We also considered complex IFP designs (an aspect of subjective complexity) to be a type of *Airspace* threat.

Table 1 lists the types of threats in our concept of airspace complexity for pilots. We applied this table of threats to our analysis of NY ASRS events. We provide examples of observable parameters associated with each individual threat in Appendix A, which is an expanded version of Table 1.

[6] See data from the FAA Air Traffic Activity System (ATADS) at Air Traffic Activity System (ATADS) (faa.gov). The total number of operations includes air carrier, air taxi, general aviation (GA), and military operations.

Table 1. Threats related to *Airspace Complexity for Pilots* at high-density airports.

Threat Type	Threats	Examples
ATC Interactions	(Lack of) clarity of communications	Confusing phraseology
	Unpublished restrictions assigned	ATC assigned speed
	Changing instructions	Clearance amendments
	Time-pressure	Difficulty reaching ATC
Flight Deck Equipment	Unexpected behavior of automated system	Trouble resolving a route discontinuity
	Time-pressured setup or configuration	Managing airspeed on descent
	Aircraft performance requires attention	Use of speed brakes
Airspace	(Complex) design of IFPs	Multiple constraints along an IFP
	High density terminal airspace design	Multiple IFPs, airport interactions
	Large amount of information to brief/know, impacting pilot tasks	Difficulty interpreting charts
Environment	Weather (of all types) that requires attention	Low visibility or shifting winds
	(High) traffic	Mix of aircraft types

4.3 ASRS Analysis

This section describes our analysis of NY ASRS events from 2019. First, we describe how the events were selected (Section 4.3.1), then how they were coded (Section 4.3.2). Section 4.3.3 describes limitations of the ASRS data and how the data were aggregated across events. Results of the formal analysis are given in Section 4.3.4. Section 4.3.5 describes some observations that we inferred from the results of the formal analysis. Finally, in Section 4.3.6, we provide an assessment of our airspace complexity threats for HDAs.

4.3.1 Event Selection

We gathered a custom set of events for analysis with the help of the NASA ASRS Program Office. The Program Office first identified potentially relevant events based on the following criteria:

1. Report received between 10 October 2019 and 31 December 2019
2. Reporter was either an Air Carrier Flight Crew, Air Taxi Flight Crew, or Air Traffic Controller
3. The associated facility was either KEWR, KJFK, KLGA, KTEB, N90 (NY TRACON), or ZNY (NY Air Route Traffic Control Center)
4. The flight phase was either Descent, Initial Approach, Approach, Final Approach, Landing, Takeoff or Initial Climb, or Climb
5. The aircraft altitude was below 18,000 feet Mean Sea Level (MSL)

There were many potentially relevant reports based on these criteria. During subsequent discussions, we agreed that ASRS expert analysts would screen and triage the full set and provide us a subset for further analysis. We provided two sample events to illustrate our needs.[7] Our final data contained 100 events with terms such as Discontinuity, Transition, Configuration, Vector, Speed Management, Go-

[7] The first sample event, accession number (ACN) 1624788, was a complicated report with ATC and pilot perspectives. This event involved multiple aircraft, go-arounds, and busy communications. The second sample event was ACN 1648852, in which the captain was unprepared for a switch to the parallel landing runway. The pilot was task saturated and the aircraft flight deck systems were not configured. The crew managed a successful landing after the captain flew the aircraft manually.

Around, TCAS, Congested, and other terms relevant to these previously listed (e.g., unstable approach). Reports that contained content relating to threats delineated in Appendix A were also included.

Our team screened the 100 events upon receipt of the narratives. We dropped reports that were too brief for analysis. We also dropped events that did not occur at or near one of the four main airports (KLGA, KEWR, KJFK, and KTEB). For example, some of the events occurred at other airports, unknown locations, or outside of the terminal airspace. The coded event also had to contain at least one HDA threat from the list in Appendix A. We dropped one report because it was purely driven by weather and it provided no insights about crew rationale/behavior.[8]

In summary, the events in our dataset occurred in the NY terminal area between October and December 2019, before the impacts of COVID-19. Our final dataset consisted of 73 events that were from one of the four major NY airports and were relevant to airspace complexity for pilots. These events involved interactions between ATC and pilots and had narratives from the pilot's perspective.

4.3.2 Method

We developed a coding rubric to classify each event (see Appendix B). The rubric was similar, but not identical, to the rubric used in Chandra et al. (2020). It included a synopsis of the event, factual data (e.g., where the event occurred and who reported it), the outcome, threat(s), context, and an explanation of the coding for internal use. We also recorded whether the pilot hand-flew during the event or used the FMS.

Two researchers reviewed each event and resolved any discrepancies. Table 1 (in Section 4.2) lists the types of threats we recorded, which were elements from our concept of airspace complexity for pilots. We referred to the airspace complexity examples in Appendix A (an expanded version of Table 1) as needed to decide how to code specific situations. We also recorded operational complexity factors (e.g., flightcrew issues) separately from airspace complexity threats.

4.3.3 Data and Analysis

The limitations of ASRS reports are well known. The events are self-reported, subjective, and written from memory. The narratives can be incomplete and difficult to interpret. They can also be biased because of difficulty in observing one's own behavior. They are not a random sample of events, so the frequency of events in the database may not represent the frequency of occurrence in actual operations. Also, ASRS reports are typically filed when there is an undesired outcome, so findings tend to be framed in terms of negatives rather than positives.

In addition, for this specific study, ASRS narratives could be difficult to interpret because they might refer to out-out-date IFPs, for which charts are not available. Without these charts, we may not know what the intended flight path should have been. Another limitation of ASRS events is that it takes a few months to process new reports, so they are not early indicators of issues that may be time sensitive.

Once all the events were coded, we entered all the fields from the coding rubric into a spreadsheet to aggregate the data across the events, and we tallied the fields. The data could be filtered to examine subsets of the data. For example, we examined events that occurred along the arrival-to-approach connection separately from other events to determine if there were any differences for these events relative to the full dataset. (This analysis is reported in Section 4.3.4.5.)

[8] Strong windshear or turbulence caused the pilot to select the wrong control, and the pilot corrected the error immediately.

4.3.4 Results

Of the 73 events, 31 occurred at KEWR (42%), 29 at KLGA[9] (40%), 8 at KTEB (11%), and 5 at KJFK (7%). Thirteen events (18%) occurred on departure, 16 (22%) on arrival, 20 (27%) on approach, and 24 (33%) while connecting from the arrival to the approach. Most of the events (58, or 79%) were reported for Title 14 Code of Federal Regulations (CFR) Part 121 (scheduled air carrier) operations. There was one event each from a Title 14 CFR Part 135 (charter) operator and Title 14 CFR Part 91 (GA) operator. The type of flight operation was not specified for 13 events. We ascertained that pilots flew with the FMS in at least 28 events (38%) and hand-flew the aircraft in at least 26 events (36%). Pilots may have only flown a portion of an event with either method. For example, sometimes pilots disconnected the autopilot and hand-flew the aircraft to resolve a traffic conflict. Thirteen events (18%) involved wind-related issues.

First, we describe the event outcomes (Section 4.3.4.1) and then we discuss the tallies of airspace-complexity threats (Section4.3.4.2). We also recorded operational complexity factors that were not airspace complexity threats. These are addressed in Section 4.3.4.3. In Section 4.3.4.4, we consider the event outcomes, airspace-complexity threats, and operational complexity factors together. Finally, in Section 4.3.4.5 we look at the events that occurred on the connection between arrival and approach to see how they compared to the overall data.

4.3.4.1 *Event Outcomes*

Table 2 lists outcomes that occurred for at least two events in the dataset. Some of these are discrete events mentioned in the narrative such as missing an altitude constraint (i.e., a vertical deviation) or receiving an alert. Other outcomes were a “state” rather than a discrete event, such as being on an unstable approach. States occur over a period of several seconds or longer; they are not transient. For example, Speed Management refers to the state where the aircraft neared the boundary of, or went out of, its desired speed state. Misconfiguration is the state where the aircraft was out of its proper configuration (e.g., flaps setting).

The most common outcomes were Vertical Deviations, Speed Management Issues, Unstable Approaches, TCAS Resolution Advisories (RAs), and Lateral Deviations. Note that a single event might have had more than one outcome (e.g., both a Lateral Deviation and a TCAS RA).

Table 3 shows a breakdown of the outcomes that occurred only once. Several of these were related to clearances or the intended flight path. For example, in one event, the crew lost sight of the runway while flying a charted visual approach.

[9] The location for the ASRS event ACN 1691679 is entered in the database as KEWR, but the narrative states it occurred at KLGA, so we coded it as KLGA.

Table 2. Event outcomes from NY ASRS dataset.

Type of Outcome	Number of Events
Vertical deviation	16
Speed management issue	16
Unstable approach	14
TCAS RA	13
Lateral deviation	10
Misconfiguration	7
Go-around	6
Terrain alert	4
Vectors required	2
TCAS Traffic Advisory (TA)	2
Landed without clearance	2

Table 3. Other event outcomes from NY ASRS dataset.

Other Outcome Category	Description
Clearances	Late landing clearance and scolding by ATC Disagreement with ATC about assigned altitude or assigned heading
Weather Deviation	Aircraft flew through heavy rain and moderate turbulence, picking their way through. They deviated from assigned heading as needed. Intentionally did not follow ATC heading to avoid weather
Flight Path	Pilot Flying (PF) lost sight of runway in final turn of Expressway Visual Flew through the localizer Delayed exit from the STAR Aircraft could not fly ILS and was cleared for the visual approach instead Crew could not establish visual contact with runway
Miscellaneous	Loss of separation Excessive difficulty (workload) flying the approach Late configuring the aircraft for position on approach Low fuel state Neglected approach and landing checklists. (Thrust reversers were not armed for landing.) ATC expected the crew to be on an assigned heading from earlier controller PF disengaged autopilot and descended to correct altitude deviation Reporter corrected possible altitude error before deviation

4.3.4.2 *Airspace-Complexity Threat Tallies*

Figure 5 shows how often each threat occurred as a percent of the 73 events in the dataset. A single event might have multiple associated threats. The frequency with which each category of airspace complexity occurred is shown in Table 4. Threats related to ATC Interactions occurred most often. There was at least one ATC Interaction factor present in 49 events (67%). This relatively high number confirms what we learned anecdotally, which is that flight operations in NY are demanding. For example, ATC issued unpublished restrictions in 14 events; 12 of these were higher than preferred speeds during descent or approach. Two were altitude constraints, one of which was assigned for a visual approach.

Airspace threats were present in 11 of the 73 NY events (15%). Interestingly, Complex Design of IFPs was mentioned by pilots in only 3 out of 73 (4%) of the NY reports. A complex IFP design might have multiple speed or altitude constraints, or one of several other factors we identified in Chandra and Markunas (2017). Such elements are often associated with Optimized Profile Descents (OPDs).

Chandra et al. (2020), found that Complex Design of IFPs was coded in 35% (i.e., 52) of 148 events analyzed at locations that had PBN IFPs (e.g., Atlanta, Northern and Southern California, and Denver). This is a statistically significant difference from the lower rate (4%) in the NY events, χ^2 (1, N = 221) = 25.17, $p < .001$. It appears that the pilots are more impacted by complex IFP designs at locations where PBN is implemented. At NY, the tactical nature of ATC may make airspace complexity less visible to pilots. The downside of the tactical approach is that it is associated with time-pressure, and potentially more frequent radio communications, and these create the potential for other undesirable outcomes. For example, pilots might miss the clearance due to frequency congestion, they may not have time to clarify an instruction, or they may run out of time to verify their automation set up, setting up future errors.

Environment factors were present in 35 of the 73 NY events (48%), whereas they were present in 36% of events in Chandra et al. (2020). The difference between these two sources of data may be the relative volumes of air traffic. Upon further examination of the data from Chandra et al. (2020), we found that traffic alone was a factor in 27% of the events from NY (20 out of 73) while it was a factor in just 12% of the events from locations with PBN (18 out of 148). This is also a statistically significant difference, χ^2 (1, N = 221) = 7.97, $p = .005$. The four major NY airports combined have more air traffic than at any of the locations evaluated in the 2020 PBN-related study; those locations, on average, have lower traffic volumes than NY. The rate of Flight Deck Equipment issues reported in Chandra et al. (2020) was 32% (i.e., 48 of 148 events), which is similar to the 30% rate seen in the NY data (i.e., 22 out of 73 events).

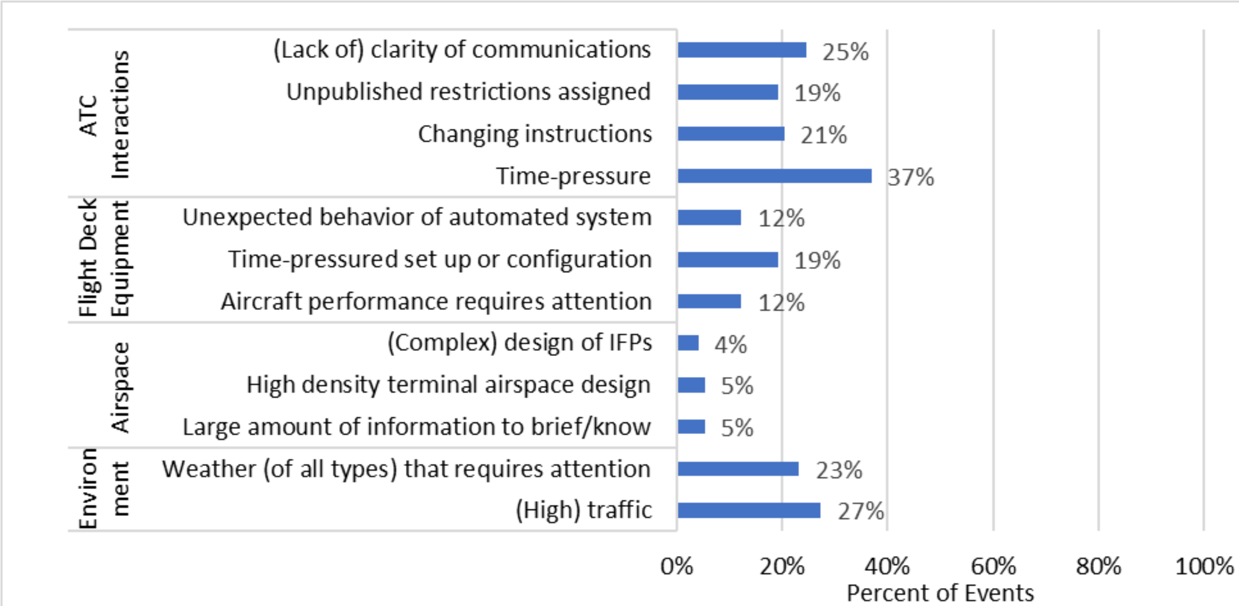


Figure 5. Prevalence of threats related to airspace complexity for pilots in the dataset.

Table 4. Prevalence of threats related to airspace complexity by category.

Threat Category	Rate of Occurrence (N = 73)
ATC Interactions	67%
Flight Deck Equipment	30%
Airspace	15%
Environment	48%

4.3.4.3 *Tallies of Flightcrew and Other Operational Complexity Factors*

Airspace complexity threats identified in the NY events were discussed in the previous section. Here we examine some additional factors we coded, specifically, flightcrew factors and internal ATC factors. Flightcrew factors were excluded from the concept of airspace complexity for pilots because they do not act externally upon the pilot, they are internal. Internal factors for ATC operations were rarely reported in our dataset because we focused on events with pilot narratives. In the previous study (Chandra et al., 2020), flightcrew factors and internal ATC factors were coded and reported. In fact, flightcrew factors were the most prevalent factor in the PBN ASRS events, with 47% of the 148 events indicating some flightcrew related factor that was relevant to PBN, and 34% of the same events indicating flightcrew factors that were not related to PBN. We did not separate the NY events based upon whether they were related to PBN or not because there were very few PBN IFPs in use at NY during the time when the events occurred.

Table 5 lists the percent of events with the most common flightcrew-related factors; we do not list factors that affected fewer than 5% of the 73 events. Notice that flight path management (FPM) is a common theme across many of these factors. Miscellaneous generic pilot errors (e.g., expectation bias) were also present in 11% of the events. Miscellaneous ATC operational errors were identified in 7% of the events, and ATC issues with aircraft sequencing were identified in 5% of events.

Table 5. Most common flightcrew-related factors in NY ASRS dataset.

Individual Flightcrew Factor	Rate of Occurrence (N = 73)
Time pressure related to FPM	19%
CRM	15%
Decision making related to FPM	14%
Distraction	12%
Lack of flight path awareness	12%
Lack of familiarity with local IFPs	8%
Confusion related to FPM	7%
Crew physical condition (fatigue)	5%

Events where flightcrews experienced time pressure related to FPM were related to events where there was time pressure associated with ATC interactions; 9 of the 14 cases had both types of time pressure. This was the strongest relation we identified between ATC Interactions and flightcrew factors. There may be a relation between ATC Lack of Clarity in Communications and flightcrew Decision Making Related to FPM; there were five events involving both factors.

4.3.4.4 *Event Outcome, Airspace-Complexity Threats, and Flightcrew Factors*

We also examined the relationships between event outcomes, airspace-complexity threats, and flightcrew factors. Table 6 summarizes the key findings of this analysis for the five most common event outcomes. Each row shows the number of events for that outcome as a function of the threat or factor in the column title. For example, there were 13 events with TCAS RA outcomes; 11 of these events involved the Environment (likely Traffic). No other threat categories were associated with TCAS RAs. In contrast, ATC Interactions, Flightcrew Factors, and Flight Deck Equipment factors were present in more than half of the events that produced Vertical Deviations. These three types of factors were also present in more than half of the events that produced Speed Management Issues and Unstable Approaches.

Table 6. Relationships between event outcome and type of threat. Cells are shaded when that threat occurred in more than half of the total events with that outcome.

	Total Events*	ATC Interaction	Flight Deck Equipment	Airspace	Environment	Flightcrew Factor
Vertical Deviation	16	**13**	**10**	4	2	**13**
Speed Management Issues	16	**14**	**9**	0	4	**12**
Unstable Approach	14	**8**	**8**	2	6	**12**
TCAS RA	13	3	2	3	**11**	1
Lateral Deviation	10	**7**	1	2	1	**8**

* The total number of events is less than the sum of the threats because each event could have multiple threats.

4.3.4.5 *Arrival-Approach Connection Events*

About one-third of the NY ASRS events (24) occurred along the connection from the arrival to approach. We analyzed these events separately to understand whether there were unique factors in these situations because we learned from Chandra et al. (2020) that this connection can be an area of risk. However, in the NY data, these situations reflected the same patterns of event outcomes and threats as the overall dataset. As with the full set, the most common event outcomes were Vertical Deviations (5), Speed Management Issues (6), Unstable Approaches (5), TCAS RAs (5), and Lateral Deviations (3).

The pattern of threats for the connection events also mirrored the full dataset. The most common individual threats were again ATC Interaction: Time-Pressure and Environment: (High) Traffic. The full list of threats for the 24 connection events is shown in Table 7. The patterns in Table 7 are the same as those in Figure 5.

Table 7. Prevalence of threats related to individual airspace complexity factors for the NY events along arrival to approach connections.

Threat Type	Threat	NY Arrival-Approach Connection Events (N = 24)
ATC Interactions	(Lack of) clarity of communications	5
	Unpublished restrictions assigned	7
	Changing instructions	6
	Time-pressure	10
Flight Deck Equipment	Unexpected behavior of automated system	2
	Time-pressured setup or configuration	6
	Aircraft performance requires attention	3
Airspace	(Complex) design of IFPs	0
	High density terminal airspace design	1
	Large amount of information to brief/know, impacting pilot tasks	0
Environment	Weather (of all types) that requires attention	5
	(High) traffic	8

4.3.5 NY Flight Operations

Additional analysis of the ASRS events yielded insights about NY flight operations in ways that were not fully captured by the tallies and airspace complexity threats. Three of these topics are discussed below, ATC airspeed management, approaches and landings in general, and charted visual approaches.

4.3.5.1 *ATC Airspeed Management*

ATC manages airspeed because it is related to compression of the spacing between aircraft and the timing of landings. From an aircraft perspective, airspeed may be related to vertical deviations because aircraft energy depends upon both speed and altitude. Speed-management issues appear to be related to ATC assigning an unpublished speed (or altitude) restriction.

More specifically, NY ATC sometimes assigned a speed that was fast for the aircraft in that situation. They also asked the crew to maintain this high speed for as long as possible with variable results. For example, there were seven events with Speed Management Issue outcomes where the aircraft exceeded 250 kts below 10000 ft altitude, which is not allowed (unless authorized by the FAA Administrator).[10] In three of these events, ATC asked the crews to expedite their departure. As the crews complied with the request to climb quickly, they inadvertently exceeded the speed restriction below 10000 ft. When ATC asked crews to maintain high speeds all the way to the end of a STAR, they had to slow down suddenly to meet the final constraint; this was not always feasible and could result in either a speed or altitude deviation. There were also events where high speeds were assigned as the aircraft was joining the approach procedure. Here, the excess speed sometimes resulted in an unstable approach.

4.3.5.2 *Approaches and Landings*

The NY ASRS events showed that sometimes ATC landing clearances are given quite late. In two events, crews decided to land without a clearance because, in their assessment, it was safer to land than to not land. Late landings and approach clearances require that pilots guess what to plan for, and if their expectation turns out to be wrong, problems could ensue. For example, they might have to reprogram the FMS under time pressure, without an opportunity to verify the changes, or they might have to turn off automated systems and fly the approach manually, which can be high workload and prone to other errors, such as an aircraft misconfiguration.

We made two other observations about landings at NY; these were about visual approaches. Visual approaches into NY airports are often not at the pilot's discretion. The timing (and resulting aircraft spacing for landings) is critical, so NY ATC often placed constraints on speed or altitude for visual approaches.[11] These constraints require pilots to manage their automated systems while meeting the timing for a visual approach, which can be tricky.

Finally, for Title 14 CFR Part 121 operations, visual approaches must be backed up by electronic navigation.[12] This revealed a subtle limitation of ASRS data. It is not clear from the ASRS narrative whether the crew is focused on the visual (out-the-window) or the electronic navigation as they conduct a visual approach. Other navigation options (e.g., an ILS to that runway) might be set up as backups to make an easy switch if needed, and in practice, crews may be focused on the electronic navigation data rather than the visual aspects of the approach.

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[10] Title 14 CFR §91.117(a), Aircraft Speed, states that "Unless otherwise authorized by the Administrator, no person may operate an aircraft below 10,000 feet Mean Sea Level at an indicated airspeed of more than 250 knots (288 mph).

[11] We asked one group of pilots about these constraints on visual approaches in our listening sessions, presented in Section 4.4. That group said constraints on visual approaches are relatively common; they are not unique to NY.

[12] See Title 14 CFRs §91.129, §91.130, and §91.131, which are regulations for operations in Class D, Class B, and Class C airspace, respectively. CFRs §91.130, and §91.131 point back to §91.129, which applies to pilots operating a large or turbine-powered airplane. These regulations state that, if the airplane is so equipped, and the runway is served by an instrument approach procedure with vertical guidance, then the pilot must fly the aircraft appropriately in reference to the glide path.

4.3.5.3 *Charted Visual Approaches*

Charted visual approaches are used in the NY area. KLGA has two charted visual approaches, the River Visual and the Expressway Visual (see Figure 6), KEWR has the Bridge Visual and the Stadium Visual, and KJFK has the Belmont Visual and the Parkway Visual. Charted visual procedures require pilots to navigate by local visual landmarks such as stadiums and tanks, which may be difficult for pilots to find if they are not familiar. The charted visuals are generally hand-flown, which can be especially challenging with crosswinds. NY ATC communications frequencies are often congested too. The combination of pilot unfamiliarity, inability to reach ATC for clarification, and hand-flying can, again, produce varied outcomes. For example, the pilot might not know the best moment to configure the aircraft. In addition, while hand-flying is sometimes preferred (e.g., when flying a TCAS RA, or mitigating the effects of an automation system that is not behaving as expected), it can also be associated with the potential for unstable approaches and misconfigurations.

4.3.6 Assessment of Airspace-Complexity Threat List

Here we offer a critique of the coding rubric we used. These insights could be helpful for the next round of improvements to the rubric for a similar analysis.

First, the threats we coded were sometimes difficult to separate from one another. For example, *ATC Time Pressure* is different from, but often correlated with*, Flight Deck Equipment Time Pressure.* It is important for reviewers to be familiar with the detailed examples in Appendix A and Table 1 to ensure that the threats are appropriately coded.

We also realized that the ATC threat "clarity of communications" could occur independently of HDAs. However, we believe it was helpful to include this threat because outcomes associated with a lack of clear communications may have a higher operational impact when the ATC frequency is busy and questions to clarify are not possible.

Finally, we found that it was sometimes difficult to determine whether factors related to the flight deck equipment were a *threat* or an *outcome* of some other threat. We counted states as "outcomes" if they occurred *as the result of* an "airspace complexity for pilots" threat. If the undesired state occurred before any airspace complexity threat, that state itself might have been the threat as opposed to being the outcome. For example, if the pilot misconfigured the aircraft inadvertently, as an error unrelated to airspace complexity, we did not code the misconfiguration as an outcome. In general, we did not see this situation here because of the way we selected the events in our dataset.

Sometimes the order of events determined whether the factor was a threat or an outcome. For example, A*ircraft Performance* might be a threat if it resulted in another outcome, such as difficulty meeting a constraint. Alternatively, if the crew had to meet an unpublished constraint (an underlying threat) then that threat could produce both a *Speed Management* outcome, along with difficulties associated with *Aircraft Performance*. In this situation, aircraft performance could be seen as an outcome rather than as a threat. The coding rubric may need to be revised to clarify this distinction.

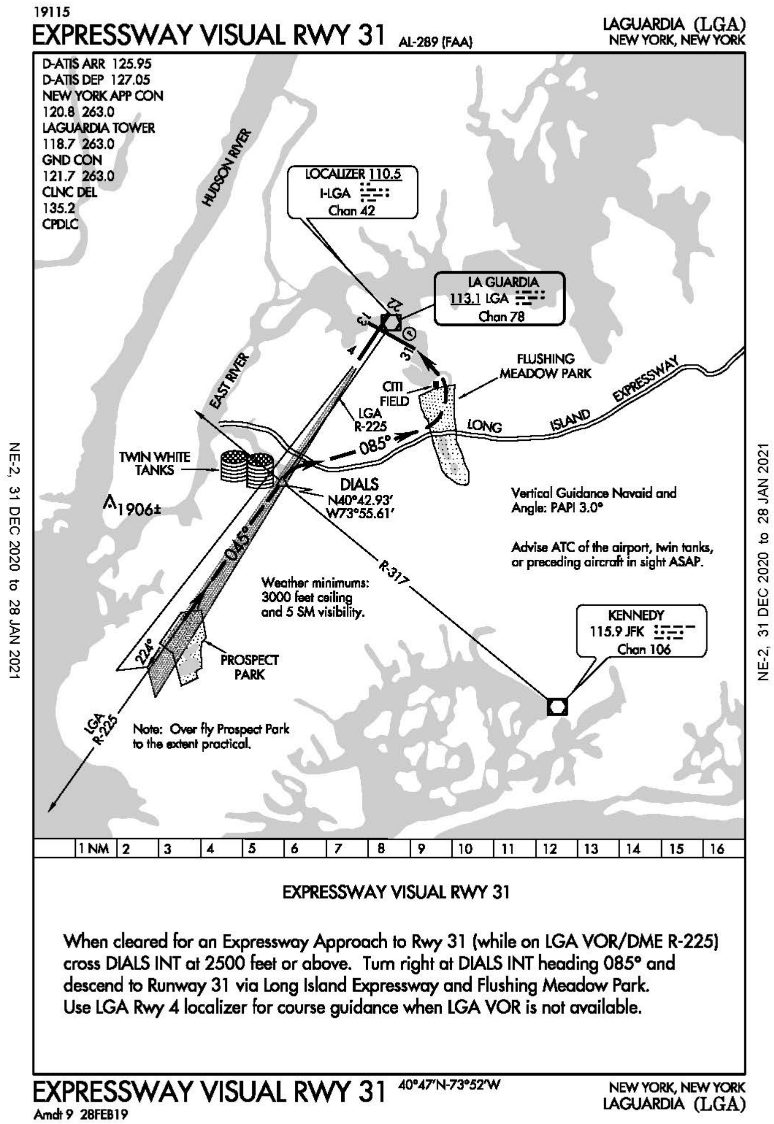

Figure 6. Chart for the Expressway Visual to RWY 31 at LaGuardia (KLGA).

4.4 Pilot Listening Sessions

The ASRS analysis presented in Section 4.3 provided a window into NY flight operations. The pilot listening sessions presented here offer another view on the same subject. We wanted to hear directly from pilots who frequently fly in the NY area. We discussed current operations and issues that were pertinent to the MARS concept, such as traffic awareness and PBN.

There are several limitations to this method of data collection. First, we gathered only subjective data. We listened to pilot's perceptions and then interpreted those perceptions. The data were nuanced. Sometimes there were similar comments across pilots, but they might be framed slightly differently. Second, the sample size was small; 31 pilots participated across 12 sessions. Finally, we gave pilots only a short abstract description of MARS at the start of the discussion. Their understanding of MARS was highly simplified out of necessity. Because the pilots had no operational experience with MARS, their input reflects only how they anticipated it might operate. Even with these limitations, the pilots' comments and questions illuminated areas that would not otherwise have come to light.

4.4.1 Participants

We advertised the study to business-aviation and airline pilots who operated in the NY area. We especially wanted to hear from "line" pilots, meaning pilots who flew on a regular basis and were not necessarily involved with NAS modernization activities. We did not reach out to pilots who flew NY infrequently. Instead, the experienced pilots described their own learning curves. The volunteers were not compensated for their participation.

We reached business-aviation pilots through the Teterboro Users Group, the Northeast Safety Roundtable forum, and businesses that operate at KTEB. To reach airline pilots, we asked four Title 14 CFR Part 121 scheduled air carriers (three major airlines and one regional) to connect us with volunteers who flew in the New York area. We offered two sessions to each scheduled air carrier and asked for a total of four to eight pilots across the two sessions (i.e., two to four pilots in each session).

Thirty-one pilots participated in the study, including nine corporate pilots, 17 from major airlines, and five from a single regional airline. Because of the format of the study, we learned different aspects of each participant's flight experience.[13] The common factor was that all of them were highly familiar with flight operations in New York, with between 4.5 and 40 years of experience in the area. Twelve participants (39%) also reported experience flying PBN routes internationally, mostly in Europe. Four pilots (13%) reported military flight experience. Seven pilots (23%) reported experience with airspace design issues. This was higher than we expected for a general population of line pilots. One explanation is that the Teterboro Users Group regularly educates their members on such issues; another is that some of the line pilots had more company responsibilities than just flying the line.[14] The sample included pilots who flew a variety of aircraft equipment including Airbus, Boeing, Gulfstream, Bombardier, and others.

4.4.2 Procedure and Analysis

Each listening session was scheduled for one hour and followed the script provided in Appendix C.[15] Two researchers took notes. The sessions were not recorded. We held twelve listening sessions in total, four with corporate pilots and eight with airline pilots. The airline sessions were comprised of six across three major carriers, and two for a single regional carrier.

[13] Pilot flight experience was self-reported and may have been incomplete. For example, some reported military flight experience. Others who had military flight experience may not have mentioned it.
[14] For example, one pilot helped to prepare the airline's airport briefing guide for the NY area.
[15] One session with corporate pilots went long by 20 minutes with the permission of the participant(s). Also, one of the corporate pilot sessions had only one pilot; all other sessions had two to four participants.

The session outline was as follows:

1. Introduction, purpose, plan, and informed consent for participation
2. Flight experience (pilot introductions)
3. Flight operations at NY area airports
    a. General
    b. Interactions with NY ATC
4. Traffic awareness at NY
    a. General
    b. Discussion of reduced separation on pairs of PBN IFPs
5. Wrap-up questions
    a. What improvements to NY flight operations are you looking for?
    b. What risks do you anticipate with implementation of PBN instrument flight procedures at NY?

The last item, about implementing PBN at NY, was a general question about risk associated with PBN IFPs, not specific to MARS. It was intended to help the FAA in developing PBN IFPs for NY in general. The researchers asked follow-up questions as appropriate for each topic.

Because the MARS proposals for NY and elsewhere are still conceptual, we did not show any of the proposed applications to the pilots during the listening sessions. We did give a general introduction to the concept of MPS, as follows, in the introduction to the study:

> The main purpose of this study is to explore flight deck issues related to flying under a proposed concept for instrument flight procedures. This concept would allow aircraft flying along specially designed pairs of PBN instrument flight procedures (arrivals, departures, and approaches) to safely fly in areas of reduced separation, which could be less than 3 NM. The FAA is considering whether and how the concept could be developed for high-density airspaces such as New York and Southern California to improve traffic flows and reduce conflicts between close-by airports.

For the analysis, we first combined data across sessions. Working one session at a time, we sorted and summarized input, by topic, into a spreadsheet workbook. Different points were made in different sessions and some points were repeated across sessions. Next, we compressed the inputs for each topic, combining similar comments and identifying particularly interesting points. In the final summary, some points were made by only one group, others were made by more than one group. Finally, we identified highlights from the full list.

4.4.3 Findings

The sections below correspond to questions in the script outline in Section 4.4.2 above. Each section starts with input from the listening sessions that confirmed what we knew about flight operations at NY based upon the ASRS analysis and discussions with industry experts. The bulk of the section then presents new insights from the listening sessions. Section 4.4.3.1 discusses general flight operations at NY. Section 4.4.3.2 is about interactions with NY ATC. Section 4.4.3.3 covers traffic awareness at NY. Section 4.4.3.4 covers input on the reduced separation concept. Section 4.4.3.5 covers input on the improvements sought for NY and the anticipated risks.

4.4.3.1 *General Flight Operations at NY*

The listening sessions confirmed much of what we knew about flying in NY. The region has busy airports close together. Familiarity with the local operations is important because it helps pilots manage workload and makes operations more predictable. There is a lot of traffic. Communications are fast paced. ATC does not use PBN often, preferring vectors and ILS or visual approaches.

Considering the high volume of traffic, NY operates well. For example, a group of regional pilots said that they appreciate NY ATC's guidance (vectors) to the approach; they miss that guidance at the smaller regional airports where they operate. Runway changes are relatively uncommon too; these can be a source of confusion and workload at airports that use PBN more, so in that regard, NY can feel more predictable to pilots.

NY is "unique" (nonstandard) in many ways, some of which were mentioned earlier, such as its geography (relative airport locations), traffic volume, and use of vectors instead of PBN. In addition, there is a great deal of local knowledge regarding, for example, local techniques for handling weather, IFP designs, ground operations, and fuel management. For example, some of the approaches use visual reference points that can be unfamiliar to non-locals. Another example is that KEWR and KTEB sometimes use circle-to-land approaches, which are practiced infrequently. A few pilots said they enjoy the challenge of flying in NY, but more of them said they would prefer lower workload flight operations.[16]

One of the challenges of flying in the NY region, which we also observed in the ASRS events, is speed management along arrivals. ATC expects pilots to keep their speeds up along arrivals unless given permission to slow. The aircraft slow down later and lower at NY, so they are flying fast low to the ground, which may feel uncomfortable. A related comment regarding the arrival-approach connection, was that there is a lot of distance between the end of the RNAV arrivals and the airport (approximately 20 NM). The participant described this as a "black hole" for the pilot in terms of flight path; the pilot does not know what to expect in the gap between the RNAV arrival and the runway. Similarly, where the aircraft will turn to join the final approach can be a mystery; there can be a long downwind. In general, pilots prefer to know their plan for joining the approach early.

Each airport at NY has its own personality, which includes local knowledge and unwritten rules. An example of local knowledge is the mix of traffic at each airport. For example, pilots from KTEB are aware of conflicts between traffic operating under Instrument Flight Rules (IFR) and VFR traffic on the edge of the airspace that can lead to TCAS RAs. There is also a significant amount of international air traffic in NY, even at KTEB. International flights may require special handling due to fuel or departure-time constraints, or because foreign pilots may have more difficulty communicating with ATC. There are a surprisingly large amount of training operations and even military operations in the NY region. There are short flights, long flights, heavy aircraft, and light aircraft. The diversity of air traffic produces a diversity of preferred airspeeds too.

Operations at NY are predictable to pilots who regularly operate in the area. To paraphrase one pilot, NY can be predictably good or bad for you. Pilots can love it or hate it for the same reason. For example, some pilots liked getting vectors while others preferred PBN IFPs. Some pilots liked the "fun" local techniques (e.g., charted visual approaches with locally known visual reference points), others preferred more standardization.

Unwritten rules, which are known to locals, can make NY a challenging area for pilots who do not fly there regularly. One example is the unwritten rule that pilots should maintain 250 kts along their arrival and approach until ATC assigns another speed or says "speed at your discretion." ATC slows aircraft

[16] For example, aircraft without VNAV and auto-throttle can be more responsive to ATC route amendments, but this can also create high workload unless pilots are familiar with the region.

down later and lower at NY, as mentioned earlier. Some unfamiliar pilots slow down without permission (so that they can begin configuring the aircraft for landing). This can cause spacing issues for ATC.

Familiar pilots also know the local weather patterns and their impacts on NY flight operations. For example, ATC can test the limits of crosswind landings because it takes time to change the airport runway-use configurations. Winds on a VMC day can cause airport delays. In addition, NY is part of the Northeast corridor, a region that is known for cascading weather delays, often due to thunderstorms. The Severe Weather Avoidance Program is only familiar to locals and can get complicated.

Another example of local knowledge is that corporate aircraft and traffic to KLGA are kept at lower altitudes for longer. Familiar pilots know to carry extra fuel. Fuel planning for NY airports is not straightforward. For example, familiar pilots know that the same flight to KLGA versus KJFK can have different fuel requirements; flights into KJFK can be vectored over the ocean for several minutes and need more fuel.

Local knowledge extends to ground operations and departure planning. There are many hot spots and bottlenecks on the ground that are familiar to locals. This is important because we heard that the departure phase can be higher workload than arrival into NY, especially if there are ground stops or weather delays. There is more pilot activity to depart (e.g., negotiating alternative departure routes).

There are different strategies to becoming familiar with NY flight operations. Our participants mentioned these strategies when recalling their own introduction to the region:

- Fly with another pilot who has more experience in the area.
- Train or instruct in the region.
- The company airport briefing guide can be helpful, if designed for both unfamiliar pilots and familiar pilots. If it is updated frequently with current issues, then it is useful to pilots who are already familiar with the area.
- Learn about the airspace design (e.g., work or interact with ATC in other ways, talk with more experienced pilots, attend Teterboro Users Group meetings).

Another theme of flying in NY that we heard, particularly from corporate pilots, is that they perceive that "best-equipped best-served" is not the guiding principle at NY. According to this principle, aircraft with better equipment (e.g., PBN-capable) will receive better ATC services. Some corporate participants said that airline operations take priority over corporate operations, even though corporate aircraft often have more advanced equipment. For example, corporate pilots flying at KTEB and Morristown Municipal Airport (KMMU) are aware of departure route conflicts between those airports and KEWR. They said that the corporate flight departures get lower priority and longer delays than scheduled carrier departures. We also heard that KJFK and KLGA appear to set the tone for the other airports and KEWR operations take priority over KTEB and KMMU. No airline participants mentioned that they felt they received worse service than any other aircraft flying into NY. Some regional pilots said the opposite, that because ATC knew they were very familiar with local operations, they might get options from ATC that other aircraft would not.

4.4.3.2 *Interactions with NY ATC*

Our conversations about pilot interactions with NY ATC also confirmed what we learned from other sources. NY ATC has fast-paced communications, they like to control "manually" (i.e., issue vectors), and they expect pilots to be responsive. Sometimes NY ATC uses non-standard, abbreviated phraseology for quicker communications, but this can be confusing to unfamiliar or foreign pilots. There is constant radio chatter, and it can be hard to break into the communications for a clarification. One pilot mentioned that at KJFK, your “check-in” is when ATC calls you. To some extent, pilots are so used to the constant chatter that silence would be uncomfortable.

The pilots we spoke to have tremendous respect for NY controllers. Almost every group mentioned that NY controllers are very good at their jobs. For example, participants mentioned that ATC is astute; they know what the aircraft can give them. Pilots said that NY ATC does a good job of separating air traffic and doing traffic callouts. Others mentioned that NY ATC is more patient with foreign pilots than ATC at other locations. However, the NY ATC style of control is not flexible. Pilots said that NY ATC does not tolerate deviations in speed or altitude; all aircraft should do the “same thing.” If negotiation is necessary (e.g., for a departure route), the pilot must clearly specify what they need and why. In general, “you get what you get.”

Some participants also mentioned ATC resistance to using new technologies and new IFPs. Some KTEB pilots, for example, brought up the Dalton VFR departure, which was coordinated with ATC to help de-conflict departures with KEWR. The pilots said that ATC still seems uncomfortable issuing the Dalton VFR departure.[17] In one of the major-airline sessions, pilots also mentioned that NY ATC is reluctant to use PBN IFPs unless the fixes are identical to existing ILS fixes. However, one airline pilot also mentioned that there is generational change in progress. There are many retirements, amongst both pilots and ATC.

4.4.3.3 *Traffic Awareness at NY*

We learned that pilots are only generally aware of traffic at nearby airports. When asked about separation from other aircraft, participants focused on longitudinal spacing along their own arrival/approach flight path. They did not mention lateral separation from air traffic operating to or from other airports.

A common source of traffic information is the TCAS traffic display. However, there is so much traffic at NY that this display gets congested. It is not easy to use the TCAS display to make sense of the traffic flows at NY. The display does not indicate which airport the flight is heading towards, where it is along its flight path to that airport, or even what type of vehicle it is (e.g., helicopter or VFR aircraft). Pilots who are familiar with the NY airspace and/or NY ATC operations may be able to understand the flows, but this is not a typical line pilot skill. For example, if the pilot knows where the other airports are (relative to the TCAS display), then they might guess where aircraft going to those location are on the traffic display.

Some pilots have access to other sources of flight data. A few mentioned they use Automatic Dependent Surveillance – Broadcast (ADS-B) In services along with their TCAS display, but this is not available to all. Participants also mentioned ForeFlight[18] software for Electronic Flight Bags (EFBs), which has a traffic layer. FlightAware is another source of traffic data available to the public. Both ForeFlight and FlightAware provide only general traffic situation awareness. One group mentioned that they also look outside the window; they cannot rely on ForeFlight but cannot ignore it either.

Overall, pilots said that ATC does a good job of separating air traffic. Light general aviation traffic, especially if operating under VFR, is more of an issue along the edges of the Class B airspace, along the

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[17] A similar example mentioned by two corporate pilot groups was that they did not understand why a departure procedure informally used by pilots departing RWY 23 at Essex County Airport in Caldwell (KCDW), to avoid conflicts with KEWR RWY 11 arrivals, was not published as a PBN IFP. They guessed that ATC objected for unknown reasons.

[18] ForeFlight - ForeFlight Mobile Electronic Flight Bag

Hudson River and shorelines, and on VMC days. KTEB pilots mentioned that they have more TCAS RAs than the other major NY airports, due to interactions between IFR and VFR traffic. Aircraft operating under VFR may be using EFBs to show them exactly where the edges of the Class B airspace are, so they are coming closer to the margins than before, increasing the potential for TCAS alerts especially at locations such as KTEB.

4.4.3.4 *Input on Reduced Separation Concept for MARS*

The participants only received a general description of the MARS concept (see Section 4.4.2). Therefore, their input on the concept is high level and speculative. We did not show any specific examples of MARS applications to the participants, and they had no operational experience with it. MARS is explained in more detail, with an example, in Section 6 of this report.

Participants were generally comfortable with the idea for reduced lateral separation (less than 3 NM) needed for MARS. They already fly with reduced lateral separation in other situations, such as for Precision Runway Monitor (PRM) and EoR approaches, both of which are in place for approaches to parallel landing runways at one airport. They also are familiar with reduced longitudinal spacing of less than 3 NM for approaches into KLGA (which has a waiver). Also, pilots comply with the published restrictions on IFPs, so if the MARS concept is based upon published restrictions, it does not change the pilot's task. Plus, pilots do not currently keep track of traffic going to other airports. It is not clear whether they should or would start doing that for future operations with MARS.

Participants identified one area of concern with MARS, which was the potential for TCAS TAs and RAs. They did not want TAs to become normalized or have an increased rate of false (nuisance) alarms. Some of the corporate pilots asked whether TCAS software would have to be upgraded to work with the reduced separation concept. The MARS development team is aware of these questions and are studying how TCAS alerts might be impacted with MARS in their safety analyses (mentioned in Section 1). TCAS alerts will be less likely when two aircraft are flying along same-direction parallel tracks, which will be the first phase for MARS (see Section 6).

Participants had many questions about the MARS concept. We did not answer these questions but gathered them for later consideration in a potential program for pilot education about the concept. For example, how will MARS function with weather in the area? In New York, small pop-up thunderstorms can cause big delays as they move through the area. In the context of deviations to avoid thunderstorms, 3 NM of lateral separation may be a relatively small margin. How quickly could MARS adapt to changing weather conditions? There was also a question about the tolerance for flight path deviations under MARS. Pilots may need to be reassured that flying a MARS IFP has the same requirements as any other PBN IFP. Other questions are listed below:

- What are the potential effects of MARS on speed management? Pilot choices about speeds vary.
- What happens in a lost-communications situation? It would be unlikely to lose communications on both aircraft, but it is easy for pilots to miss a communication.
- How will pilots learn about the MARS concept in general? Pilots want to be educated and informed; how remains to be determined.
- How will pilots be made aware that MARS operations are in effect? Participants were particularly concerned about the transition/testing period for MARS at NY. They pointed out that change introduces more risk than the final configuration. It might be helpful to make pilots aware of any trial phase, perhaps by giving a key word on the Automatic Terminal Information Service (ATIS).

- Would an operator need a Letter of Authorization or Operations Specification to fly a MARS operation? If not, make that clear.
- Wake turbulence and rough rides might be an issue with reduced separation. How will MARS avoid the potential risks associated with wake turbulence?

Participants also had other thoughtful comments about the reliance of MARS on PBN IFPs. Their comments apply generally to PBN IFPs, not just to the MARS PBN IFPs. First, participants pointed out that some aircraft (particularly on regional airlines) do not have VNAV. While VNAV is not technically required to fly IFPs with multiple vertical constraints, pilots know that without VNAV the workload associated with PBN IFPs can exceed the pilot's capabilities. Better equipped aircraft would be more able to handle complicated IFP altitude and speed constraints. On a related note, ATC should not be expected to know which aircraft are able to fly the new PBN IFPs. In addition, new PBN IFPs need to be usable by ATC; that means that ATC should feel comfortable issuing them knowing that they will be accepted. If, for example, the use of the PBN IFP is limited to specific times (due to noise abatement rules, for example) or certain aircraft (due to equipment requirements), they may not be issued at all.

Participants also mentioned that reduced separation and use of PBN IFPs to support MARS requires changes to the communication patterns with ATC at NY. For example, would there be verbal traffic callouts of the traffic on another IFP? If yes, that could lead to more communication congestion. On the other hand, if all goes as planned with implementation of PBN, there should be less radio traffic overall. There might be a period of transition where pilots who are used to the constant radio chatter of today get used to the quieter frequency.

Finally, one group pointed out that passengers sometimes report when another aircraft was too close during their flight, even if it was a normal operation. It is conceivable that passengers may notice the MARS traffic more than pilots.

4.4.3.5 *Input on Developing PBN at NY*

Participants reaffirmed two known aspects of flying with PBN in this portion of the listening sessions. First, PBN reduces communications with ATC; it can also reduce communication-related errors. Second, as mentioned earlier, PBN arrivals are easier to fly with VNAV than without. Auto-throttle/autothrust capability is also helpful in combination with VNAV for flying PBN arrivals.

Some of the participants look forward to PBN at NY, and its concomitant standardization of flight operations. Some of the participants know that PBN is the necessary way forward to increase the efficiency and safety of flight operations at NY but they were less enthusiastic about it than others. Regional pilots expressed satisfaction with current operations. Their older FMS equipment may have more challenges with flying PBN IFPs.[19]

The participants also pointed to improvements that would help operations at NY that were independent of PBN. Standardizing and codifying current procedures and communicating unwritten rules would be helpful in general. For example, our participants said that the vectors that ATC issued were often repeated and predictable. If so, could they be codified in published IFPs?

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[19] Corporate pilots brought up another example of PBN issues related to old equipment. In some old FMSs, the manufacturer logic is to show only the approach with the lowest weather minimums, which is the RNAV (GPS) Y at KTEB. However, ATC prefers to use the RNAV (GPS) X because it decouples traffic between KEWR and KTEB. The RNAV (GPS) Y creates conflicts with airspace, but all the FMSs show it. There is a mismatch between what is easiest for the pilot and what is best for ATC in this situation.

Similarly, could the speeds that ATC expects be published? We found that the expectation to fly at 250 kts on the arrival is written in a chart note on two of the three arrivals to KTEB. The note says "Advise ATC prior to speed reduction below 250 Knots" on the Wilkes-Barre 4 STAR and the JAIKE 3 RNAV STAR, but not on the MAZIE 3 RNAV STAR. The note is not on the arrivals to KLGA or KFK, even though at least the KORRY into KLGA is well known (to familiar pilots) for this expectation.

Pilots also have other needs at NY that could be addressed independently of PBN. For example, they would like to see improved departure sequencing and transparency about departure routes and negotiation. They mentioned that negotiating with ATC about departure routes can be delicate and not everyone has the same data about the situation. Sometimes there are communication issues between ATC and pilots, which could be helped with use of Controller-Pilot Data Link Communications (CPDLC). There are also internal ATC communication issues; some of the smaller NY airports do not have digital ATC communications, for example, and may still be using phones. Another area for improvement at NY is the predictability of operations when there are thunderstorms. Finally, two groups made a point related to improving the customer experience. Prominent customers flying business-aviation jets out of Teterboro, for example, may wonder why their departure is delayed on a sunny day; the explanation may have to do with what is going on at Newark, which is not satisfying. Airline passengers into NY can also run into unexplained lengthy delays and ground stops.

The participants expressed some concerns with implementation of PBN at NY. One comment was that change introduces more risk than the final configuration; the transition phase will be tricky. There is a need to build trust in the system, but there will be a learning curve. Also, pilots would prefer a clean cutover to PBN, not a mix or evolution. A mix of PBN and current operations may be more difficult in terms of setting pilot expectations. It would also help to update the communication capabilities at NY along with PBN; both work in concert to improve the system. Also, each airport will have its own challenges, including the smaller airports. Another potential concern with PBN is that ILS approaches may still be required because they can handle lower weather minimums than RNAV approaches. If weather issues create delays, ATC may revert to vector-based control, and it may be difficult to re-sequence aircraft on PBN IFPs.

Finally, participants pointed out that both pilots and ATC will need to be educated about new IFPs, airspace changes, changes to any requirements, and potential links to other new initiatives (e.g., miles-in-trail operations). How to educate pilots about the new concepts, including MARS, is to be determined. Several ideas were proposed (e.g., ATIS, an Attention All Users Page, or a briefing bulletin). The goal would be to provide sufficient background on the new concept without being overly intrusive.

5. Resilient Pilot Behaviors

We explored resilient pilot behaviors as a supplementary goal of this project (see Section 2). The current effort was an extension of a preliminary analysis that was part of a previous study where we studied operational complexity using ASRS events from locations with PBN (Chandra et al., 2020). In the older study, we assessed whether the ASRS narratives had sufficient content to be able to identify safety-related pilot behaviors that indicated crew resilience. We concluded that ASRS event narratives do, in fact, contain evidence of resilient pilot behaviors (e.g., reallocating tasks between crewmembers effectively or notifying ATC in advance and requesting relief from a flight path constraint).

The previous study connected adaptive expertise and resilient behaviors (Chandra et al., 2020). Resolving operational complexity in real situations requires flexibility and adaptability, which we see as features of crew resilience. Chandra et al. (2020) recommended that:

> …the FAA, operators, and flightcrews should promote and cultivate a culture of "adaptive expertise" amongst pilots. Adaptive experts are able to apply knowledge effectively to novel or atypical situations (Hatano & Inagaki, 1986). They are more flexible and innovative than "routine experts" who are experts at applying known procedures/checklists for problem solving. (Chandra et al., 2020, p. 21)

This time our goal was to develop deeper insights about resilience by analyzing these behaviors after gathering them.

We describe our approach to studying resilience in the NY events in the next section (Section 5.1). Our analysis is described in Section 5.2. Section 5.3 contains our assessment and recommendations about studying crew resilience using ASRS data.

5.1 Approach

We examined the NY ASRS event narratives to study resilient pilot behaviors. We began by recording any evidence of resilient pilot behaviors while filling out the coding rubric. We used an informal definition of resilience for our initial scan, to highlight behaviors that enhanced the safety of flight in notable ways. We adopted a liberal approach, keeping all potential resilient pilot behaviors for later analysis after all the events were coded.

At least two reviewers examined each event narrative. The first recorded any behaviors they perceived to be resilient. The second reviewer confirmed or debated the first reviewer's selections. Sometimes, reviewers recorded their level of confidence in classifying the behavior as resilient or noted whether the behavior was novel or routine.

Reviewers discussed the borderline cases of resilient behavior as a team. We decided that our working definition of resilience should capture behavior that required creativity or "intelligence" in making a decision. If the behavior followed the only reasonable or required path, that was less interesting from the perspective of adaptive expertise, even if it added safety in that situation.

Based upon this informal method for collecting resilient behaviors, we found 28 of the 73 events (38%) described a resilient behavior that we wanted to analyze further. The other events (more than 60%) did *not* describe behavior we considered to be indicative of adaptive, flexible flightcrew behavior.

Although the flightcrews did demonstrate safe behaviors in other events, that behavior may have been standard or routine in that type of situation. We considered, but eventually gave up, the notion that the crew was resilient merely because they filed an ASRS report (as opposed to, for example, having an accident or incident occur). We decided that filing an ASRS event did not indicate resilience that went "above and beyond" routine safety-oriented behavior. We also discussed some *categories* of borderline cases. For example, not every decision to go-around indicated resilience; sometimes a go-around was the only safe option. Other borderline behaviors included having a good visual scan for traffic or choosing when (or whether) to turn off the automated system and hand-fly the aircraft. Sometimes, for example with a TCAS RA, hand-flying was required and did not involve tradeoffs.

We analyzed our collection of resilient behaviors through the lens of two different models. The models are described by Pruchnicki et al. (2019) in a literature review on flightcrew procedures for unexpected events that addresses resilience. These models and their application to our data is discussed in the next section.

5.2 Analysis

A recent newsletter from the NASA ASRS Office (NASA, July 2021) addresses aircrew resilience. It begins by trying to define the term but acknowledges that this is an active area of research and there is no widely accepted definition yet. The newsletter provides this rough definition for context:

> Generally speaking, Aircrew Resilience comprises qualities and attributes exercised by a pilot or crew that enable one to rebound and recover from inflight disturbances or adversities, particularly those that demand a high degree of resourcefulness, anticipation, creativity, or situational awareness, and then return to stable, desired flight parameters and aircrew performance in an acceptable period of time. (NASA, 2021)

Pruchnicki et al. (2019) present several models of resilience. One well known model was developed by Hollnagel and others (Hollnagel, 2009; Hollnagel et al., 2015). A key premise of this model is that behaviors that reinforce safety should be identified and studied. These behaviors are associated with *Safety-II* as opposed to *Safety-I*. Safety-I is the more long-standing approach; it promotes the reduction and prevention of unwanted outcomes that result in failures and harm. Safety-I behaviors (e.g., errors that cause accidents) are relatively unusual, but well documented. In contrast, Safety-II behaviors may be highly prevalent, but largely go unrecorded. The goal of studying Safety-II is to promote and spread positive behaviors that enhance safety.

NASA is engaged in several projects related to studying Safety-II (cf. Holbrook, 2021; Mumaw et al., 2021; Feldman et al., 2021; Stephens et al., 2021). These projects collect instances of Safety-II behaviors. Their operational definition of resilient pilot behaviors is broad. It is intended to identify all kinds of teachable lessons for pilots. The various projects examine data from different sources. Feldman et al. (2021) reviewed ASRS events. One of their goals is to develop a detailed taxonomy for behaviors that promote safety. Such a taxonomy may be necessary for analysis of large numbers of ASRS events via machine learning and natural language processing.

Feldman et al. (2021) provide examples of classifying resilient behaviors in ASRS events using the Hollnagel model. They use the Hollnagel Resilience Analysis Grid (RAG), which is a technique for identifying and operationalizing different types of Safety-II resilient behaviors (Hollnagel, 2011; Hollnagel, 2015). The RAG classifies behaviors as *anticipating, monitoring, responding,* or *learning*, which are the four "cornerstones" of the Hollnagel model. (These behaviors are also explained in Pruchnicki et al., 2019.) The RAG technique is inclusive of all types of safety-oriented behaviors, trying to capture all pilot contributions to safety. In contrast to our approach, Feldman et al. believe that almost every ASRS report is evidence of resilient crew behavior because "operators survived the event and were able to write the report" (p. 123). American Airlines' Department of Flight Safety (2020) also used the RAG to study safety-producing behaviors in their operations. American Airlines also uses a broad definition of resilient pilot behaviors, echoing NASA's goal of documenting all kinds of teachable lessons.

Our first step in analyzing the resilient behaviors collected from the NY ASRS events was to classify each of the resilient behaviors in terms of the four Hollnagel cornerstones. This was not a difficult exercise; it was easy to place a behavior into one of the four categories because the RAG model is essentially time-based. The "first" behavior the pilot might engage in is anticipation, then monitoring, then responding, then learning. So, *when* the behavior occurred within the event was often related to what type of behavior it was.

While the RAG could successfully classify a resilient behavior, it did not yield new insights about adaptive expertise. The RAG was not helpful in separating routine pilot safety-enhancing behaviors from unusual ones. We also found that it left standard behaviors, such as following checklists and SOPs, inside the

Safety-II set of behaviors. While it is true that following checklists and SOPs enhance safety, we felt that these were not contributions of the individual, rather they were contributions set in place by the operator. When a SOP is not available, it is the pilot's decisions, creativity, and intelligence that will matter. We were interested in behaviors that extended safety beyond the baseline, perhaps even cases where the pilot was able to produce an outcome that exceeded standard expectations.

As a result of these mismatches with the RAG model and our goal for analyzing resilient behaviors, we sought alternative models that would highlight behaviors related to adaptive expertise and human contribution. For example, we considered assessing the behaviors in the event narratives based on some measure of the "quality" of pilot performance. The idea was that pilot behaviors vary; many pilots are solid performers who follow all rules and know many techniques for accomplishing their goals, but some think "outside the box." However, the assessment idea depends on knowledge of typical professional pilot behaviors. Assessment could be inconsistent depending upon the reviewer's background knowledge and expertise. In the American Airlines' (2020) study, the reviewers were themselves pilots and flight instructors. They also had real-time access to the subjects of their review. These are better conditions for developing a constructive way of identifying and reinforcing positive safety behaviors by pilots; ASRS data are not suited to such assessment.

We finally developed an alternative scheme for coding resilient pilot behaviors based on the work of Dekker and Lundström (2007). Their work was more in line with our ideas of adaptive expertise. They developed indicators of resilient crews "who are capable of recognizing, adapting to, and absorbing threats and disturbances that went outside what they and their training were designed for" (p. 261).

The Dekker and Lundström (2007) resilience indicators are listed in Table 8. The left column in this table summarizes the concept from the original work. Unlike the Hollnagel cornerstones, these indicators will not be present in most or all events. Another distinction is that the Dekker and Lundström indicators emphasize the decision-making process. There are some intuitive relationships between these indicators and the Hollnagel model, however. For example, *fragmented problem solving* may be related to deficient *monitoring*. Continuous *risk assessment* may also be related to *monitoring,* and it could be related to *anticipating* as well. Lack of, or misapplied, *learning* may also be related to situations where crews *infer future safety from past success*, or where crews who *assume that past situations were too different* from the current one to apply what they learned.

The Dekker and Lundström (2007) resilience indicators can be separated into two categories. Some of them are more likely to be observed in self-reports than others. The second column in Table 8 makes this distinction. Some behaviors (e.g., how a crew handled a decision involving sacrifices) are more likely to be articulated in a self-reported narrative because they were probably made consciously and proactively. Some decisions, such as taking past success as a guarantee of future safety, may not be made consciously, and hence may not be self-reported. We also suspect that longer ASRS narratives would illustrate these resilience indicators whereas shorter narratives may not have enough context to understand the pilot's decision-making rationale.

Table 8. Resilience indicators from Dekker and Lundström (2007).

Resilience Indicator Dekker & Lundström (2007)	Self-observation	Example Evidence
How does the crew handle sacrificing decisions?	Possible	Did the crew take small losses in order to invest in larger margins? How much are they willing to borrow from safety to achieve faster, better, or cheaper service?
Is the crew keeping a discussion about risk alive when everything looks safe?	Possible	Is the crew actively engaged in risk analysis, even when all looks safe?
Is the crew open to generating and accepting fresh perspectives on a problem?	Possible	Crew generates hypotheses, considers fresh perspectives, openly debate rationales for decisions, reveal hidden assumptions.
Has the crew invested in the possibility of role flexibility and role breakouts?	Possible	Did the crew actively consider how roles are to be handled in planning for unusual situations (e.g., go-around)?
Does the crew take past success as a guarantee of future safety?	Less likely	Crew might make assumptions based upon past experiences that may not be valid in the active situation, or they might report specific safety assumptions they did not make.
Does the crew distance themselves from possible vicarious learning through differencing?	Less likely	Did the crew assume that other situations are irrelevant because of some differences, even when there are lessons to be learned?
Is the crew's problem solving fragmented?	Less likely	With incomplete information, crew may not recognize gradual erosion of safety.

We easily applied the Dekker and Lundström (2007) resilience indicators to our NY ASRS data, at least for the behaviors that could be self-reported. Of the 28 events with some resilient behavior, 17 showed some evidence of the Dekker and Lundström resilience indicators for pilot reports. The fact that some of the events were not relevant makes sense because of our liberal approach to collecting the behaviors.

The most common resilience indicator we found was continuous risk assessment, which was identified in all but two of the 17 events. For example, in ACN 1696101, the crew said that a previous aircraft had done a missed approach. As a result, they assessed that their own risk of a missed approach had increased, and they planned for a missed approach in the event they could not get the attention of the ATC Tower and a landing clearance. Another example of risk assessment was in ACN 1703565, where the captain delayed a turn towards an aircraft operating under VFR that they were aware of; they knew that the turn would put them in a conflict with that aircraft.

Two of the events were situations where the pilots demonstrated the ability to break out of their roles to improve safety (ACN 1693377 and ACN 1704326). In ACN 1704326, a relief pilot actively contributed and helped the crew to avoid an altitude deviation. More interestingly, there were two examples of this within ACN 1693377 where the pilot adopted the viewpoint of the controller. First, the pilot used the traffic display to notice that they were asked to descend to a lower altitude than the aircraft they were following. The pilot stopped the descent, then queried ATC. This was a proactive decision that not all pilots would have made. The decision was based on the context provided by the traffic display and the busy communications frequency. The second example, in the same event narrative, is that the pilot reporter noted that they were asked to stop their descent after they were cleared for the ILS approach. The reporter then volunteered that a visual approach would be acceptable, helping by taking the perspective of the controller. This was a discretionary action that allowed the aircraft to continue the approach rather than being circled around to try for another ILS approach, which would have been more work for ATC. The pilot anticipated potential resolutions to their situations and quickly offered one that was acceptable to both the flightcrew and ATC.

There were three events where the pilots demonstrated the ability to make sacrificing decisions. In two of these, the crew made the decision to land without a clearance because they deemed it safer than a go-around. These events also demonstrated continuous risk assessment. Both events (ACNs 1709721 and 1709891) described the crew's rationale for their decision to land in detail. This was not necessarily an obvious choice. In ACN 1709891, for example, the pilot reports considering several elements (e.g., traffic spacing, ambient visibility, visual examination of the runway, and inability to reach ATC). Some pilots would have decided to go-around, which might have caused more confusion. Not all pilots would have been as thorough in comparing the alternatives. In ACN 1709721 the pilot also demonstrated an ability to take the controller's perspective.

Separately, in ACN 1691679, the pilot could see a situation developing that was taking the controller's attention: a departing aircraft was still on the runway. The crew decided to purposefully overshoot the final approach course on the Expressway Visual at KLGA and do S-turns to create space and time for the controller. This demonstrated an ability to see the situation from the controller's perspective (role breakout), as well as continuous risk assessment, sacrificing behavior, and a fresh perspective in deciding to do S-turns, which are not commonly used in Part 121 operations. To be fair, this choice was not without risk (of turning into an unstable approach) and it may have been outside of company standards, but we point it out here because it was an example of a fresh perspective in any case.

5.3 Assessment

We analyzed resilient crew behaviors that appeared in the NY ASRS data using two models, the Hollnagel RAG (Hollnagel, 2011; Hollnagel, 2015) and the Dekker and Lundström (2007) resilience indicators. The Dekker and Lundström resilience indicators suited our analyses better than the RAG because they were focused on behaviors that indicated adaptive expertise. We were interested in adaptive expertise because of prior work on operational complexity (Chandra et al., 2020), for which flexibility and an ability to think beyond the SOPs is important. We wanted to make a distinction between the safety behavior that the "best" pilots demonstrate relative to the safety behavior of the pilot who only follows the SOPs.

We learned from this exercise that it is important for researchers to think about how they intend to use the results of the resilience analysis. That purpose will drive how to operationalize the concept of resilience. NASA's goal, for example, is to identify *all* safety behaviors. The NASA projects seek a comprehensive understanding of how pilots contribute to system safety, with the end goal to understand how much of a contribution they make to overall system safety. Secondarily, NASA aims to classify and organize the safety behaviors that pilots perform. Classifying the safety behaviors was lower priority for our purpose of identifying behavior that was adaptive.

This exercise also made us even more sensitive to the limitations of ASRS data, which were discussed in Section 4.3.3. The ASRS narratives offer an incomplete picture of resilient behaviors. For example, while the narrative may describe some resilient behaviors, there may have been resilient actions that the reporter did not mention for whatever reason; perhaps they were unaware of their own behavior, or they wanted to limit the time they spent preparing the report. Longer narratives tended to explain more about the decision-making process so they may have been seen by reviewers as having more evidence of resilient behaviors simply because of how they were written. The narratives were also not suited to more detailed analyses, such as a separate analysis of team versus individual contributions to resilience. Those analyses would require inferences that cannot be substantiated. Finally, the selection criteria for the ASRS events might affect whether resilient behaviors are observed. Chandra et al. (2020) found that events where the outcome was *No Deviation* typically mentioned a resilient behavior. In these events, there was no deviation usually because the flightcrew took an action to prevent it. None of the NY ASRS events had “no deviation” as an outcome because they were selected on the basis of their outcome (Section 4.3.1).

We also learned from this exercise that no “observer” of resilient behavior is perfect either. Observers introduce their own biases and assumptions (e.g., their knowledge of “standard” pilot behaviors, their own flight experience in that type of situation). Even within a small well-functioning research team, the analysts did not always agree on what was a resilient pilot behavior. The process of coming to an agreement about what was a resilient behavior did not always converge. An individual analyst would sometimes reverse their own assessments of resilient pilot behaviors upon re-reading the narrative. Individual analysts could see why a particular behavior might or might not be considered relevant. It was easy to make a case for why a particular behavior might (or might not be) resilient.

It is not clear how best to ensure that analysts are consistent, both internally, and amongst each other. One way to address the problem is illustrated by the American Airlines’ study (2020). Their observers were experienced pilots and flight instructors. Some of them were trained observers. The team also iterated on their observation recording sheet, honing it for consistency and ease of use. In that effort, the observers also interacted with the pilots, so they had access to more real-time data about the situation, not just a static self-reported narrative.

We conclude that ASRS events have some use in validating the existence of resilient behaviors, but they have significant limits too. The data are abundant but time-consuming and labor-intensive to analyze. Our project only examined 73 events. Depending upon the goal, this sample size may be too small to produce new insights. Perhaps with machine-learning techniques it will be possible to process ASRS data in bulk, but that is a big task. NASA’s approach, to seek data about resilient behaviors from other data sources, is also worth pursuing in parallel.

6. MARS

We introduced MARS briefly in Section 1. Here we describe the MARS concept in more detail (Section 6.1). Section 6.2 introduces some basic IFP design concepts that are necessary for understanding the proposed MARS applications. Section 6.3 has our preliminary thoughts on analyzing one specific notional geometry from the MARS Operational Concept (FAA MARS ConOps v1, 2019).

6.1 Proposed MARS Applications

The MARS concept proposes a way to alleviate adjacent-airport flight-path conflicts such as those described in Section 4.1 for NY. Figure 7 compares a generic EoR application on the left to a generic MARS concept (or *application*) on the right. In both images, there is an area of reduced separation between parallel segments of authorized IFPs where the aircraft are separated by less than the standard

3 NM. The right side of Figure 7 illustrates how MARS would de-conflict the IAPs at two airports, A and B. If the aircraft were flying straight-in approaches, their paths would intersect. Building curved paths to the runways allows the aircraft to turn to final later because they would already be established on a published IFP.

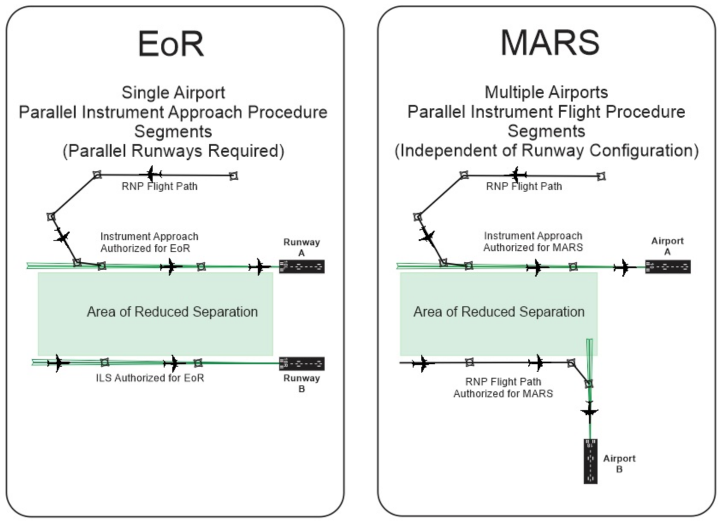


Image adapted from the FAA MARS ConOps v1 (2019)

Figure 7. Comparison of EoR (left) and MARS generic applications (right).

Once aircraft are established on the MARS IFPs, ATC would monitor aircraft conformance to the IFP (i.e., apply MPS procedures), providing intervention as needed to correct for potential deviations. With EoR, which is at just one airport, a single controller is assigned to both approaches. As MARS is currently envisioned, separate Tower controllers would handle each IFP (because they are going to different airports) but the number of TRACON controllers would depend on the spacing between the IFPs (FAA MARS ConOps v1, 2019).

MARS can pair any combination of IAPs, SIDs, and missed approaches. It may also create new route segments that attach to existing conventional IFPs, such as ILS approaches. MARS can accommodate individual pairs of IFPs or combinations of three or more paired IFPs. The FAA will conduct six phases of MARS safety analyses, each one corresponding to a different combination of IFP types. The six phases are:

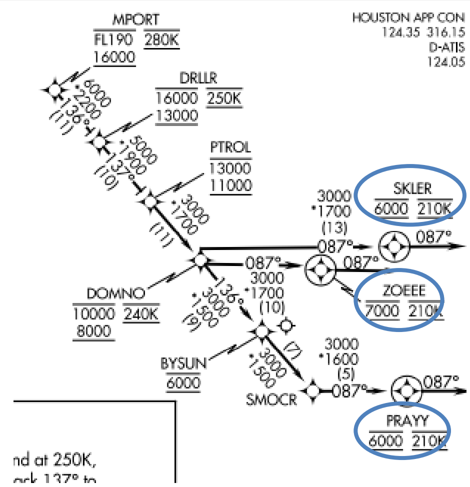
1. Same-direction, approaches with two controllers
2. Same-direction, approaches with one controller
3. Same-direction, departures
4. Same-direction, missed approach and departure
5. Same-direction, approach and departure
6. Opposite direction

6.2 IFP Design Basics

In this section, we discuss some general IFP design features and some features that are specific to PBN.

Terminal IFPs (STARs, SIDs, and IAPs) could be designed with either conventional (ground-based) or satellite-based navigation waypoints. Both STARs and SIDs consist of *common routes* and *transitions*.

The common route of the STAR (or SID) is the same path regardless of where the aircraft is coming from or going to specifically. Transitions are branches off the common route that go to different points. Enroute transitions define the path between the common segment and the enroute airspace. On a SID, runway transitions define the path from the runway to the common segment of the SID. On a STAR, runway transitions define the path from the end of the common route to the runway or to the feeder route that connects the STAR to the IAP.

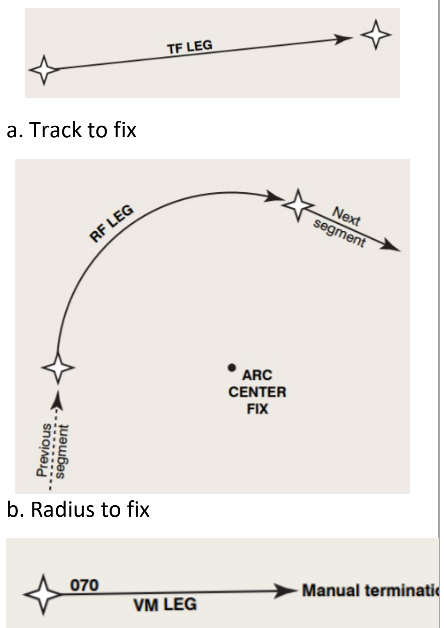


Excerpt of DRLLR 5 at George Bush Intercontinental Airport (KIAH) in Houston

Figure 8. Example RNAV STAR with three runway transitions (circled).

Figure 8 shows three runway transitions (circled) on an excerpt of an RNAV STAR. Each of the three runway transitions connects to different IAPs via feeder routes. Feeder routes are transitions to the runways on an IAP. Pilots call “feeder routes” *approach transitions*; this is how they are often labeled on the FMS. Controllers do not have a separate name for runway (approach) transitions; to them, the approach transition is part of the approach clearance.

There are many ways to connect two points in space with PBN. The ARINC *leg types* are defined by their path and termination points and are coded into the aircraft navigation system (FAA Instrument Procedures Handbook; FAA, 2017). For example, a track-to-fix (TF) leg follows a straight track between two fixes. A radius-to-fix (RF) leg connects two fixes with a constant arc defined by the radius from a separate point in space (the arc center fix). A heading (or vector) to a manual termination (VM) leg follows a specified heading until ATC clears the aircraft to a new point. These examples are depicted in Figure 9. For more examples, see the FAA Instrument Procedures Handbook (FAA, 2017).



a. Track to fix

b. Radius to fix

c. Heading (vector) to manual termination

Images from the FAA Instrument Flight Procedures Handbook (FAA, 2017)

Figure 9. Example IFP leg types.

PBN IFPs may have many waypoints and constraints. Constraints are limits on what speed and/or altitude the aircraft can be at each waypoint. *Mandatory* constraints are “hard” altitudes or speeds (e.g., cross at 6000 ft). *Window* constraints specify a range of altitudes or speeds (e.g., between 6000 and 8000 ft). A constraint could also be in the form of a minimum or maximum value (e.g., an altitude or speed that the aircraft must be at or above/below).

Another distinction is between fly-over waypoints and fly-by waypoints, illustrated in Figure 10. Fly-over waypoints require the aircraft to fly directly over the waypoint before starting a turn to the next waypoint. With fly-by waypoints, the aircraft can start the turn early and cut the corner. Fly-over waypoints are used to skirt nearby obstacles (or restricted areas); they apply hard constraints. Fly-by waypoints allow shortcuts, which might be flown differently by different FMS boxes. Fly-by versus fly-over waypoints therefore change the lateral flight path. If there are speed or altitude constraints on the fly-over or fly-by waypoint, the aircraft energy state could also be affected.

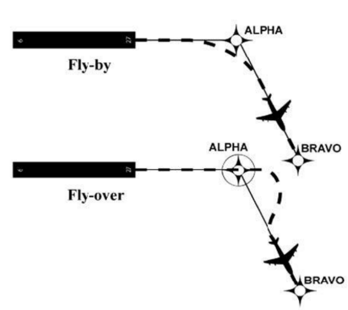


Image from the FAA Aeronautical Information Manual, (FAA, 2021)

Figure 10. Fly-by versus fly-over waypoints.

6.3 Assessment of Notional Application

We selected one proposed MARS application for review (Figure 11). This figure shows a proposed concept for deconflicting the existing ILS approach to RWY 22R at KJFK (Figure 12) from a new proposed RNAV (RNP) approach to Runway 31 at KLGA. The box marked as "area of reduced separation" in Figure 11 is where MPS would be in place. It represents a separation of greater than 9000 ft, but less than 3 NM (i.e., 18000 ft).

The waypoints shown along the KJFK ILS 22R approach in Figure 11 are defined today, so they are also shown on Figure 12. MATTR is the final approach fix (FAF) and has a mandatory altitude of 1900 ft. CORVT is the IF and requires an altitude of 3000 ft or higher. Interestingly, Figure 12 also shows an RNAV transition to the ILS 22R at KJFK. The IAF for this transition is CIMBL, then the transition crosses over the field before taking left turns up to LEFER, from which the aircraft would join the ILS. This nicely illustrates how an RNAV transition to an ILS would look on a chart. All the waypoints on this RNAV transition are fly-by waypoints, as indicated by the waypoint-symbol shape used on the chart.

ALPHA, BRAVO, CARLY, and DELTA in Figure 11 are placeholders for the waypoints that would define the proposed new RNAV approach transition (i.e., feeder route) to KLGA Runway 31. CARLY has an altitude constraint of 1900 ft in this proposal; we presume this is a mandatory altitude. Safety analyses in progress will determine the feasibility of this concept in terms of the exact positions of the proposed waypoints, its vertical flight path, and any potential speed constraints. The safety analyses will consider the different types of aircraft that might fly this transition. They may also consider whether any proposed RF segment could be replaced with multiple TF legs; use of TF legs will expand access to a broader set of aircraft than use of an RF segment, which requires special aircrew and aircraft qualification.

A note in Figure 11 says that ATC will issue vectors to the IAF (on the new proposed RNAV transition) from various existing STARs, both RNAV and conventional. This means that the STAR to IAP connection will require ATC to issue vectors to join the STAR to ALPHA, which appears to be the IAF that starts the RNAV transition. Conventional STARS do not have the lateral precision that RNAV STARs have, so their end points may be more variable. ATC vectors will compensate for this variability. As the aircraft joins at ALPHA it is very important that its energy state matches the speed and altitude constraint at the IAF, shown as 3000 ft and 210 kts. ATC vectors (and any prior issued unpublished speed constraints) must align neatly with the constraints at ALPHA every time, without deviation.

From a pilot's perspective, some considerations and questions for the design of the new RNAV transition are:

- How long is the final approach leg into RWY 31 at KLGA? The distance should give pilots sufficient time to complete all final checklists without concerns about flight path changes. An ILS approach typically has a straight final approach segment that is about 6 NM long. (For example, the approach in Figure 12 has a 5.7 NM final approach segment.)
- By when should the pilot have the clearance to land via this RNAV transition? At what point should they break off the approach if they have not received a clearance to land?
- Is ALPHA the IF or IAF? If it is the IF, are there other transitions with unique IAFs that join at ALPHA?
- Will ALPHA, BRAVO, or CARLY be fly-over or fly-by fixes? (DELTA, the FAF must be a fly-over fix.)
- Will BRAVO or CARLY have speed constraints, and if so, will my aircraft be able to meet those while also descending and slowing down?

- As the aircraft flies from ALPHA to BRAVO, its flight path vector will converge with the approach path to the ILS 22R at KJFK. How likely is this to cause a TCAS TA or RA against an aircraft traveling to KJFK along the ILS 22R along that segment?
- Is it possible that ATC would vector aircraft on to the ILS 22R at KJFK from the west, traveling across the RNAV transition into KLGA RWY 31? Could that cause a TCAS RA or TA?
- Will there be a charted note indicating that the IFP is part of a MARS operation?
- Will the pilot of either the KLGA or KJFK procedure be required to have any special knowledge, e.g., of breakout procedures, or ATC phraseology during a MARS operation?

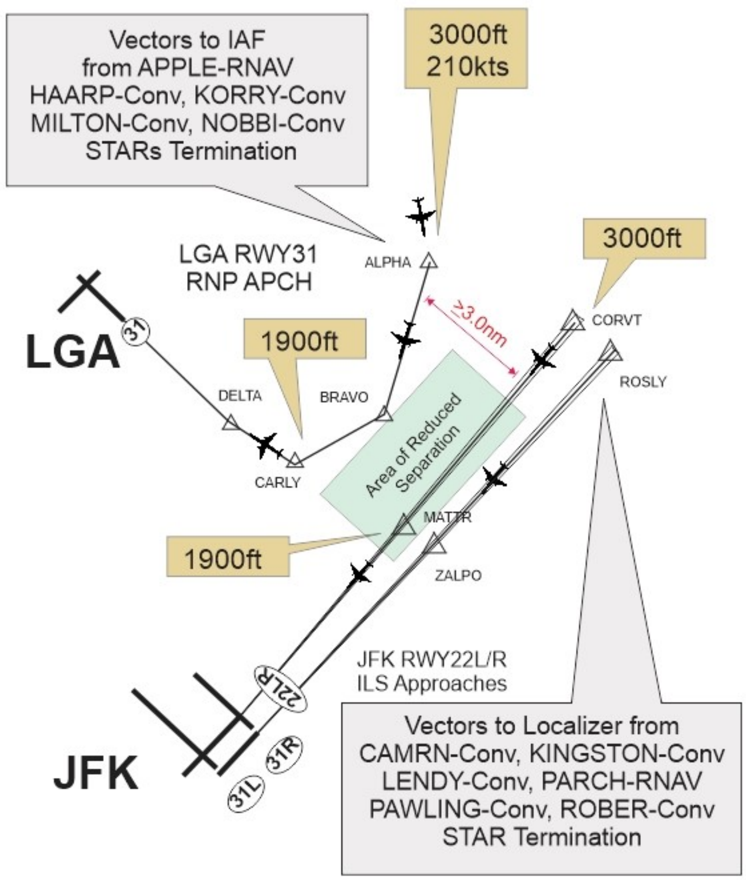


Figure 11. Notional MARS application for de-conflicting LGA RWY 31 approaches from JFK RWY 22L/R ILS approaches.

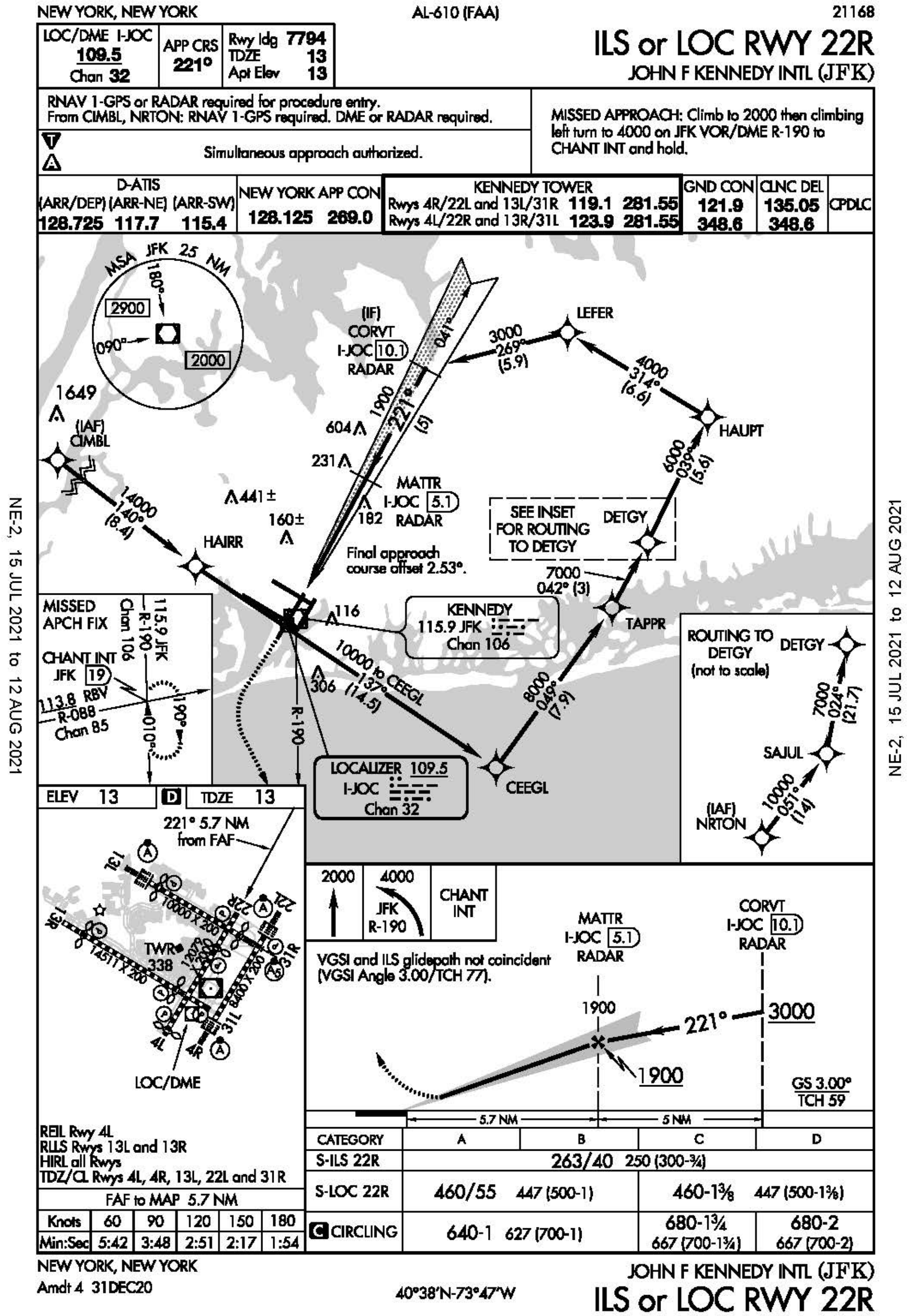


Figure 12. Current ILS 22R chart for KJFK.

The questions above reflect the general guidance provided on IFP design in Chandra and Markunas (2017). Some pertinent highlights from that general guidance about IFP design, operational complexity, and chart design, are provided below. Some of these issues will be considered in the safety analysis (e.g., IFP design recommendations) but others may not appear until later stages, such as when charts are being developed for initial implementation. While charting issues may appear to be far in the future, the earlier they are considered, the smoother the implementation will be.

IFP Design Recommendations

- Minimize path constraints. Constraints create pilot workload during reviews and briefings. They must be reviewed if the route is amended. Pilots must actively manage and monitor constraints in flight (e.g., the constraints at ALPHA and CARLY). Workload of managing constraints can vary greatly depending on the aircraft equipment and its ease of use.
- Minimize flight path transitions. Transitions add variability to the flight path, they add visual complexity to charts, and they add a decision point for pilots. This is why the pilots must know whether they are cleared for the approach from a particular transition as early as possible.
- Ensure that energy profiles are smooth between adjoining IFPs and/or segments of IFPs. Pilots manage and monitor aircraft energy as they climb and descend. The flight path should allow a smooth climb and descent, without sudden changes that surprise the pilot. This is why the entry point (ALPHA) constraints must be met even as the aircraft is vectored on to the transition to KLGA.
- Waypoint names should be pronounceable, short (with few syllables), and, ideally, familiar. Pilots review waypoints in their crew briefings, which are quick and focused. Awkward waypoint names take extra time and may create confusion. ALPHA, BRAVO, DELTA, and CARLY are evidently not the final waypoint names. The final names should adhere to this recommendation.
- Minimize and prioritize notes. Be aware of the intended audience and write the note for that audience. Pilots learn to ignore notes if they do not apply. MARS may (or may not) require additional training on phraseology or limitations of the procedure that could end up as notes. If pilots are not exposed to or authorized for these procedures, the notes could be perceived as clutter.

Recommendations Related to Operational Complexity

- IFP designers should assume that one or more operational complexity factors will be a factor in normal operations. The IFP should be designed to absorb normal operational variations. Do not assume best case conditions for normal operations. For example, ATC frequency congestion is a known issue at NY (Section 4). How might this affect operational implementation of the MARS application?
- IFP designers should be better informed about aircraft equipment variation and flight deck tasks and perspectives. There is a large variation in the types of aircraft that fly to NY, from smaller aircraft (e.g., Title 14 CFR Part 91 aircraft and commuter/regional aircraft) all the way to large wide-body international carriers. MARS PBN IFP should be tested for a broad range of aircraft.

Joint IFP Design and Chart Recommendations

- Determine how and where to chart new transitions on IFPs. Sometimes it makes sense to add runway transitions to the STAR, for example, but other times, those same segments might be easier to use if they are part of the IAP. For example, the early Boise RNAV (RNP) approaches were eventually split into separate IFPs because they were trying to combine features of both an arrival and an approach into a single IFP.

- Clarify and separate notes based on purpose. Determine whether the note is for action or awareness, and consider whether the two types could be separated for pilots. Notes for action are more important to flight crews than notes for awareness. If pilots only need to be aware of MARS operations, but their actions are unaffected, those notes may be less important.
- Reduce the overall number of notes. Determine whether the chart is the best means for conveying specific notes or if another location or method of communication would be better. Determine whether some notes are no longer useful and remove these. Do not add a lot of notes related to MARS; they could reduce the salience of existing notes.

7. Operational Complexity and IFP Connections

In Section 3.1, we described the concept of operational complexity. Operational complexity is associated with ATC interventions, flight deck equipment (e.g., aircraft automated systems), crew factors (e.g., knowledge, training, and experiences), operator factors, and environmental factors. Operational complexity affects all flight operations, including operations at HDAs. It also affects how pilots manage their route and how they use aircraft automated systems to do so. Operational complexity must be managed in real-time. For example, pilots and controllers must work together to resolve operational difficulties during ATC clearance amendments.

We know from Chandra et al. (2020) that PBN appears to magnify the impacts of operational complexity. MARS relies upon new PBN IFPs. For example, MARS will require new connections between arrivals and approaches at HDAs (FAA MARS ConOps v1, 2019). Conventional or RNAV STARs could connect to new (or existing) RNAV transitions, RNAV approaches, or to conventional approaches. For example, an RNAV STAR could connect to an ILS approach, or a conventional STAR could connect to an RNAV approach. We reviewed an example proposed connection for NY in Section 6.3. With HDAs in regions such as NY, which already have complex ATC operations (e.g., fast-paced communications), adding PBN to the mix could increase operational complexity further (see Sections 4.4.3.4 and 4.4.3.5).

Connections from arrivals to approaches can be tricky with PBN IFPs because of the crew’s reliance on automated systems to fly the precise routes. If ATC changes the route (i.e., issues a revised clearance), pilots may have to reprogram and reverify the route in the FMS, which takes time and care in a time-sensitive portion of the flight. Although a connection might be well designed for optimal situations, there may be unanticipated difficulties in real operations. Previous analyses (Chandra et al., 2020), input from subject-matter experts (SMEs) in the PARC PCPSCI working group, and experience from the EoR trials confirm that this connection is an area of risk for PBN IFPs.

We described examples of operational complexity encountered during trials of EoR, which has similarities to MARS, in Section 3.2. Thomas et al. (2018, 2019) found that reprogramming the FMS was an issue for flightcrews. Reprogramming the FMS poses risks in terms of timing and accuracy of the flight path. Even the language used by ATC for EoR operations is different from that used by pilots; pilots are unfamiliar with the term EoR. The ATC phraseology that describes the arrival-approach connection may also need to be standardized for PBN IFP connections. The phraseology currently used to assign RNAV transitions, for example, is known to cause confusion because, as mentioned earlier, pilots expect the term “approach transition,” which is unrecognized by ATC; ATC uses the term “runway transition” for the same idea.

Here we explore the impact of operational complexity on arrival-approach connections. Section 7.1 provides background on some of the difficulties. The Arrival-to-Approach Subgroup of the PCPSI is working to develop recommendations for issues related to operational complexity and connecting flight paths. We summarize their discussion topics in Section 7.2.

7.1 Background

In Section 3.1, we describe results from an analysis of PBN-related ASRS events (different from the NY ASRS events discussed earlier). The analysis was based on a small set of reports that pertained to ATC Interventions, Aircraft Equipment, and IFP design at locations with PBN IFPs. Section 7.1.2 analyzes how pilots handle ATC clearance amendments on the flight deck, describing the information they need, when they need it, and the decisions they make. This analysis provides context on why the revised clearances for connections can be difficult to manage. Section 7.1.3 discusses the lateral geometries that can connect a STAR to an approach.

7.1.1 Analysis of PBN-Related ASRS Events Along Arrival-Approach Connections

We identified a small subset of PBN events related to arrival-approach connections for further analysis from the larger set of ASRS events analyzed for Chandra et al. (2020). That report found that crew-related factors were the most common operational-complexity factor in PBN-related events in general. In the full dataset, 26 events of out of 164 (16%) occurred during a connection from an arrival to approach.

We recoded these connection events using the updated rubric for this study (Appendix B). In the process of recoding for airspace complexity threats with the new rubric, we separated out events that were primarily due to crew-related factors, which are internal rather than external threats. We did this to focus on potential implications for MARS. We then narrowed the analysis further, to only include events for which the main threats included ATC Interventions, Flight Deck Equipment, and/or IFP Design (a subset of the Airspace threat). These threats were deemed most relevant to the operational complexity of PBN IFPs. Some of the events we included also had secondary environmental threats. We excluded events that were primarily due to environmental threats.

Our final dataset consisted of 18 PBN ASRS events on connections from arrivals to approaches that occurred in 2017-2018. Table 9 shows the main threat type(s) for each of the 18 events. Some of these events involve STARS that are still current. We attempted to expand this set with more current events, but it was difficult to identify newer events that were so narrowly scoped. We searched for events related to connections identified by pilots from the PCPSI working group but could not find corresponding examples in the ASRS database. As a reminder, limitations of ASRS data are discussed Section 4.3.3 and Section Assessment5.3.

This group of PBN ASRS events yielded a different pattern of outcomes from the full dataset of PBN events. Altitude deviations were the most common outcome in the full dataset but here the most common outcomes were Lateral Deviation (6), Vectors Required (4), and Excessive Workload (4).

Table 9. Main threat types in 18 selected PBN connection events.

Main Threat Category or Categories	PBN Connection Events (N = 18)
ATC Interactions Only	7
ATC Interactions and Airspace (IFP Design)	6
Flight Deck Equipment Only	4
Airspace (IFP Design) and Operator[20]	1

Table 10 shows the individual airspace-complexity threats coded for the 18 PBN ASRS connection events. The sum of threats does not add to 18 in Table 10 because a single event could have more than one associated threat. A comparison of Table 10 with data for NY events (Table 7) shows that Complex Design of IFPs was more common in the PBN connection events (10) than in the NY data (none). This reflects similar findings comparing the PBN and NY data that are reported in Section 4.3.4.2. Also, ATC unpublished restrictions appear to be more prevalent in the NY connection events (7) than the PBN connection events (2). Other types of ATC interventions, including changing instructions and time pressure appeared to be roughly equivalent between PBN and NY connection events. Finally, unexpected behavior of a flight deck automated system appeared to be more common in the PBN connection events (6) than in the NY connection events (2). We did not test these differences statistically due to the small sample size of the datasets.

Table 10. Prevalence of individual threats in 18 selected PBN connection events.

Threat		PBN Connection Events (N = 18)
ATC Interactions	(Lack of) clarity of communications	7
	Unpublished restrictions assigned	2
	Changing instructions	6
	Time-pressure	7
Flight Deck Equipment	Unexpected behavior of automated system	6
	Time-pressured setup or configuration	9
	Aircraft performance requires attention	2
Airspace	(Complex) design of IFPs	10
	High density terminal airspace design	4
	Large amount of information to brief/know, impacting pilot tasks	4
Environment	Weather (of all types) that requires attention	3
	(High) traffic	2

[20] In ACN 1413979, there was a potential for a clearance to an approach that was not authorized by the operator. The operator had removed the RNAV (GPS) approach from the navigation database due to past unstable approaches. However, it is listed on a chart note as the one pilots should "expect" and proceed along if no other approach clearance is issued.

One example from this PBN connection dataset illustrates how many factors can be involved in a single event. ACN 1347601 had eight coded threats, including all three airspace design factors, plus a weather situation that created time pressure in using the flight deck equipment. Unclear ATC communications, ATC time-pressure, and changing instructions rounded out the threats. The aircraft, operating under Part 121, was attempting to land at Dallas Love Field during a thunderstorm. The crew asked for a diversion to the nearby Dallas-Fort Worth airport. They were assigned the visual approach to RWY 13L, but they were unfamiliar with the local area and did not realize that both airports have a RWY 13L. ATC had not heard the request for a diversion and was continuing to vector them to Dallas Love Field through the storm after the crew was unable to load the STAR that ATC assigned. (The HIBIL STAR to Dallas Love was unfamiliar and the crew could not find it in their FMS.) The outcome was a go-around after the crew realized, based upon the runway lighting configuration, that they were at the wrong runway. The main factors (from a PBN perspective) in this event were judged to be ATC interactions and IFP design, although weather was also clearly a driving environmental factor.

7.1.2 Handling Route Amendments in the Flight Deck

PBN IFPs work well when the pilot knows the plan and executes the plan. The pilot can set up the automated systems as required, verify the set up, then monitor these systems as they manage the flight path without intervening. Managing an ATC clearance amendment can impose time-pressure and workload on pilots, so pilots prefer to know the plan early, but sometimes ATC needs flexibility to change the cleared route. Pilots might get a route amendment at the last moment. If they do not handle the clearance amendment accurately in time, they might fly a path that was not cleared by ATC or become confused and uncertain about what path to fly.

The connection from an arrival to an approach is particularly time sensitive. ATC needs flexibility at that stage to achieve the desired spacing between arriving aircraft. There is a need for a compromise between advance planning required by pilots and late fine-tuning that ATC needs. Some changes that ATC might need to make include issuing (a) a new runway assignment, (b) an alternate runway (approach) transition to the same runway, or (c) altering the type of approach without changing the assigned runway. Any time the runway or the type of approach is amended, the pilot must recheck whether the aircraft systems will be properly set up (including planning for a missed approach if necessary). The aircraft must also be properly positioned for the new approach in terms of aircraft configuration, spatial position, and energy management. Even a “simple” switch to a parallel landing runway can trigger checks for the pilot because the runway length, runway navigation aids, surface conditions, etc. could change. Sometimes ATC issues more than one clearance amendment for the approach in a row; this can create especially high workload for pilots.

Figure 13 illustrates the steps that pilots go through when receiving and handling an ATC clearance amendment. Starting from the left side of the figure, the first action is that the pilot receives new instructions. Even this initial step might fail; for example, if the ATC communications frequency is busy the pilot can miss the call. When received, the pilot is responsible for reading the new clearance back to ATC to ensure they heard the instructions correctly.

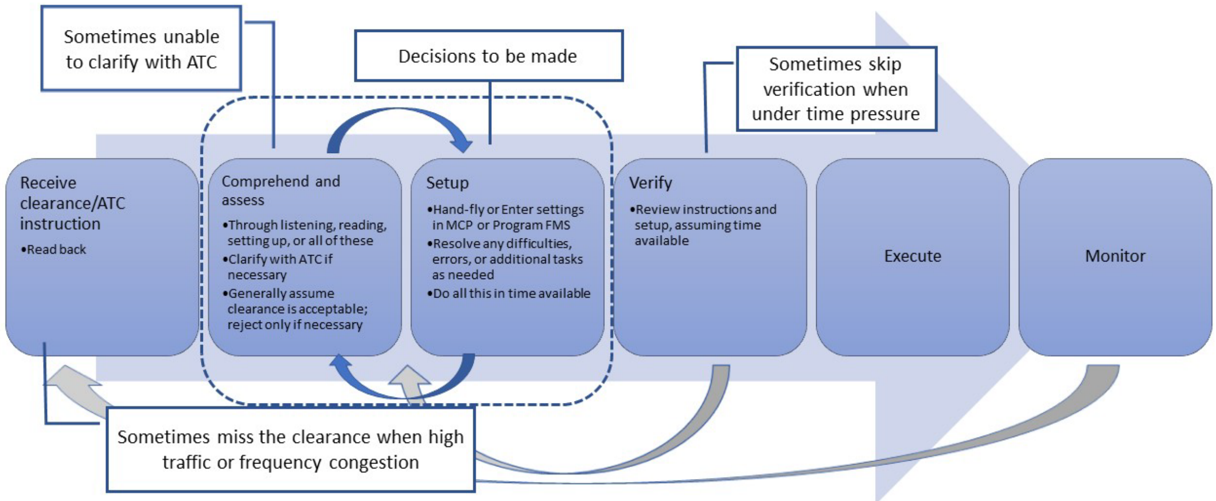


Figure 13. Pilot perspective on handling an ATC clearance.

Reading back is helpful, but it is not the same as comprehending and assessing the clearance. Pilots begin to understand the clearance as they hear it and read it back. They continue to assess the clearance by listening, reading, and discussing the clearance with the other crewmember. They continue this process as they set up the new instructions in their flight deck automated systems. If an issue comes up, they may go back to ATC to clarify the instructions. Even as pilots are working to understand the new clearance though, their assumption is that the clearance is acceptable; they want to comply and will only reject the clearance if necessary.

As they comprehend and assess the clearance, the pilot begins to set up the aircraft to fly that new route. The pilot must decide how they intend to comply with the new route. Will they enter settings into the Mode Control Panel (MCP) or reprogram the FMS? Will they hand-fly the aircraft or use the autopilot? Will they use the flight director? The pilot may hand-fly when a quick response is needed (e.g., to a TCAS RA) or when they want to practice manual flight operations. The pilot may use the MCP when a medium amount of responsiveness and precision is necessary. For example, they may set an initial heading while setting up the FMS. The pilot may use the FMS when flying RNAV routes or routes that have (lateral, vertical, or speed) constraints or published turns and altitude changes. The FMS is also the preferred platform when electronic navigation is necessary across a longer distance (e.g., STAR or SID). Debugging FMS programming errors can take time, but it is worth the effort if the aircraft stays on the programmed route for a long distance, or if precision is required.

Another decision the pilot makes when setting up for an approach is what type of navigation to use. In Section 4.3.5.2, we mentioned that all visual approaches flown by Title 14 CFR Part 121 aircraft must be backed up with an electronic navigation source for vertical guidance. Therefore, even when flying a visual approach, the pilot must have some approach set up on the aircraft. Many FMSs allow the pilot to set up two options, a primary and a backup. Pilots try to use the backup to pre-load an alternate approach that they might get. If they guess correctly, ATC will issue a clearance for the approach the pilot loaded as either the primary or secondary approach. If they are unlucky, ATC will clear them for an approach that is not set up as either primary or secondary, which will induce much more workload on the pilot. Because of this calculation, pilots must decide not just *what* approaches to setup in the FMS, but also *when* to select their best guesses.

The number of steps to complete and verify the setup of aircraft systems will vary based on these choices. All these decisions and tasks, including resolving any errors or side-tasks, must be completed within the time available. Sometime new tasks appear during the process; the extra tasks increase subjective complexity (Chandra & Markunas, 2017). For example, an issue setting up the clearance might require pilots to go back and review the clearance to be sure they understood it correctly. Thus, comprehension, assessment, and setup can be a loop as indicated by the arrows and dashed box in Figure 13.

Once the setup of the new clearance is complete, then the pilot moves to the verification step, where they confirm the instructions and setup. For example, if the pilot gets a revised approach type, the verification step involves confirming all the altitudes and waypoints for the new approach. If all goes well at this point, the pilot moves on to the execution and monitoring steps. Unfortunately, pilots sometimes skip the verification step under time pressure, which can lead to errors that are only detected later.

Timing is a challenge with the process of handling a clearance amendment. The amount of time available to handle a clearance amendment goes down as distance to airport decreases (for both arrivals and departures). Time pressure also increases with increased traffic in the area. HDAs have more traffic than other locations, so they may be prone to time-pressure associated with air traffic. Areas such as NY have a lot of traffic. NY ATC also issues vectors to pilots in rapid sequence, and they count on flightcrews to respond quickly to ATC instructions.

7.1.3 Lateral Connection Geometries

In this section we delve into the lateral geometries associated with entering an airport traffic pattern (see FAA AIM Section 4-3-2, 2021). It is important to understand what happens inside the traffic pattern because the end of the STAR must join cleanly to the pattern for a smooth landing. Figure 14 is taken from the FAA AIM. It shows a generic traffic pattern to a single runway, with departure, crosswind, downwind, base, and final approach segments.

Figure 15 shows the generic ways of entering a landing pattern for a single runway. The runway is in the center right of the diagram. A straight-in entry comes in from the left, at little or no angle relative to the runway final approach course. A base entry comes in at a 90° angle to the final approach course. The left-base entry means that the aircraft takes a left turn to join the final approach and a right-base entry means that a right turn is executed. Base entries are used on RNAV approaches with the "Basic T" design (FAA AIM Section 4-5-5-d, p. 5-4-9). Some RNAV STARs transition directly to conventional ILS approaches. For a conventional ILS or localizer-only approach, the entry is at an angle less than 30° from the final approach course. Downwind entries are opposite heading from and parallel to the runway final approach course. As with base entries, downwind entries can be from the left (standard) or from the right (nonstandard) direction. A 45° intercept angle is common for joining the downwind, but it could also be joined directly.

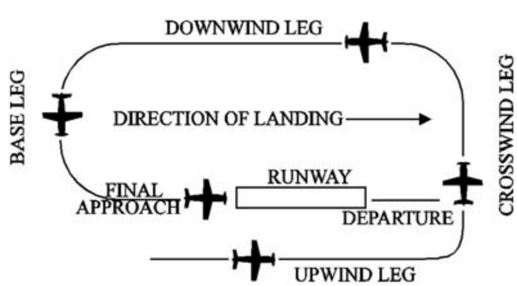


Figure 14. Generic traffic pattern components from FAA AIM, Figure 4-3-1 (2021).

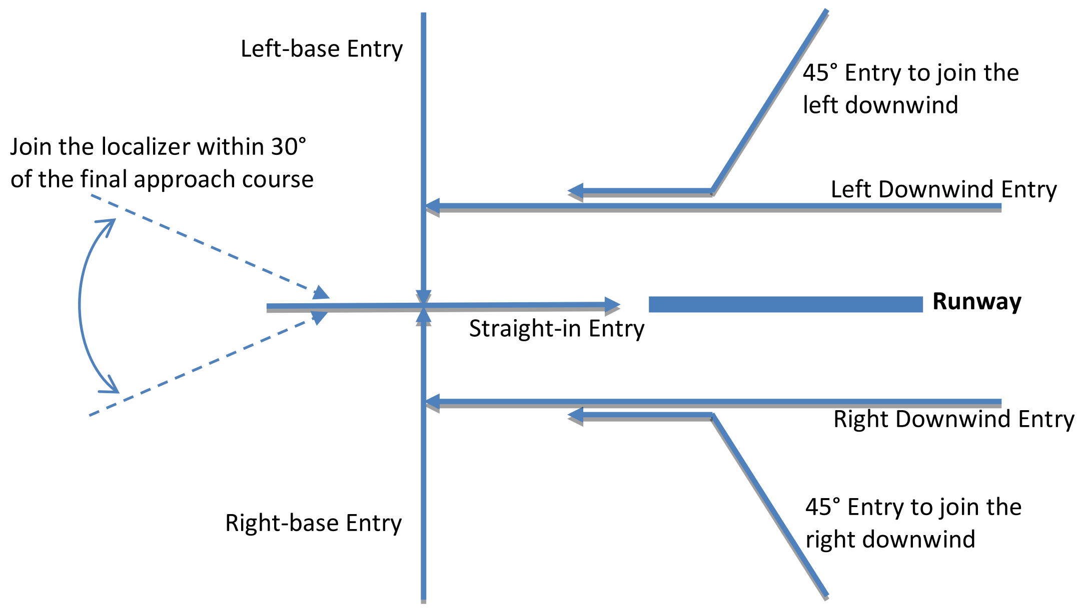


Figure 15. Directions for entering the airport pattern for a single runway.

There are three common leg types that terminate an RNAV STAR. These are the VM, which is a heading to a manual termination, fix-to-manual termination (FM), and TF legs.[21] The VM leg ends the STAR with a specific *heading*. This might be the straight-in-heading to the runway, or it could be a heading for the downwind. It could also be at an angle to the runway approach course if the STAR serves more than one runway direction. An FM leg ends with a specific *track* over the ground. A TF leg terminates at a fix, which may have associated speed and/or altitude constraints. The termination fix could be either a fly-over or fly-by waypoint, but it is often a fly-over waypoint.

Figure 16 and Figure 17 provide an example of a STAR and its terminations for Baltimore/Washington Thurgood Marshall International Airport (KBWI). Figure 16 shows the graphic depiction and Figure 17 shows the text version of the path. The airport has two long runways, 10/28 and 15R/33L, and one shorter runway, 15L/33R. It has four RNAV STARs, ANTHM 3, MIIDY 2, RAVNN 6, and TRISH 3. ANTHM has four runway transitions that all end in VM legs (Figure 16). A VM leg is shown as an arrow with a heading in this FAA chart.

The terminating waypoints for ANTHM are HOIST, HOOOK, RAAYY, and GRAMZ. All are fly-over waypoints as indicated by the circle around the four-pointed star symbol. HOIST ends in a heading of 285° and can join to any of three runways landing east (10 and 15L/R). The VM leg at HOIST leaves the aircraft on a downwind for RWY 10, but at a 130° angle relative to RWY 15L/R. The terminating heading at GRAMZ is 105°, which is the downwind heading for the westbound RWY 28. HOOOK serves the westbound runways 33L/R.

[21] In an early 2021 summary of RNAV STARS used at the core 30 airports in the United States, AFS-430 reported that 299 terminated in FM legs, 72 terminated in TF legs, and 74 terminated in VM legs. *(Personal communication from FAA AFS-430.)*

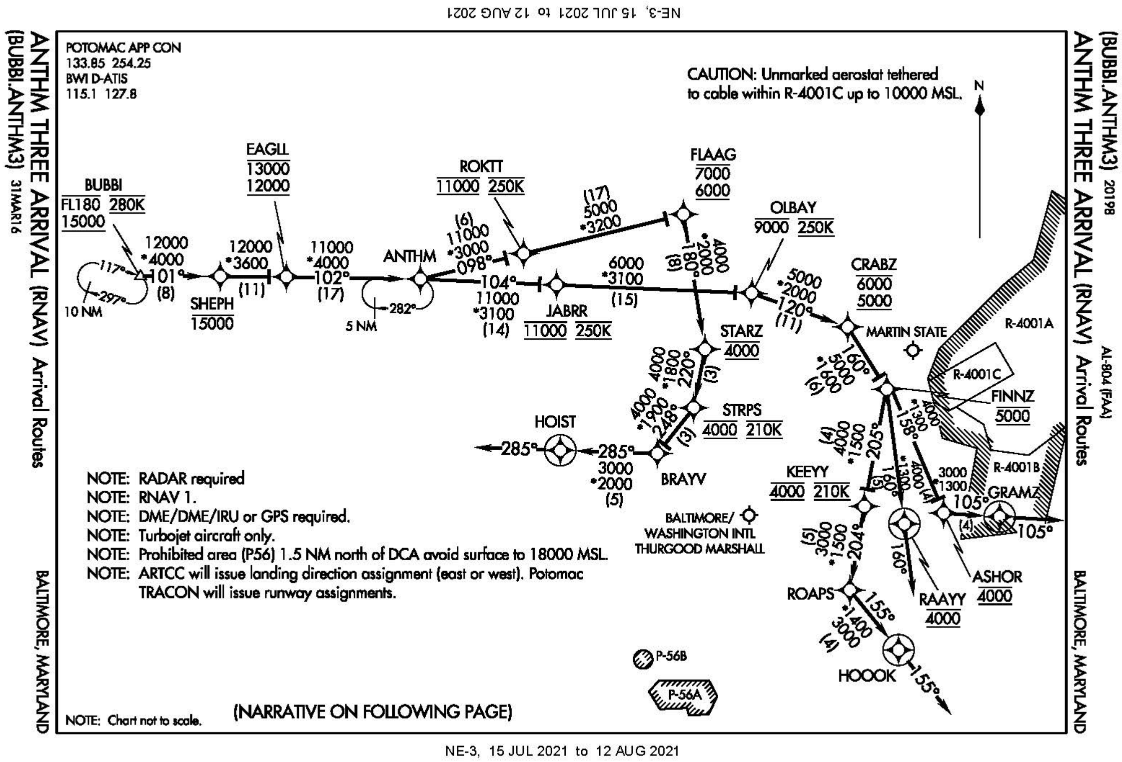
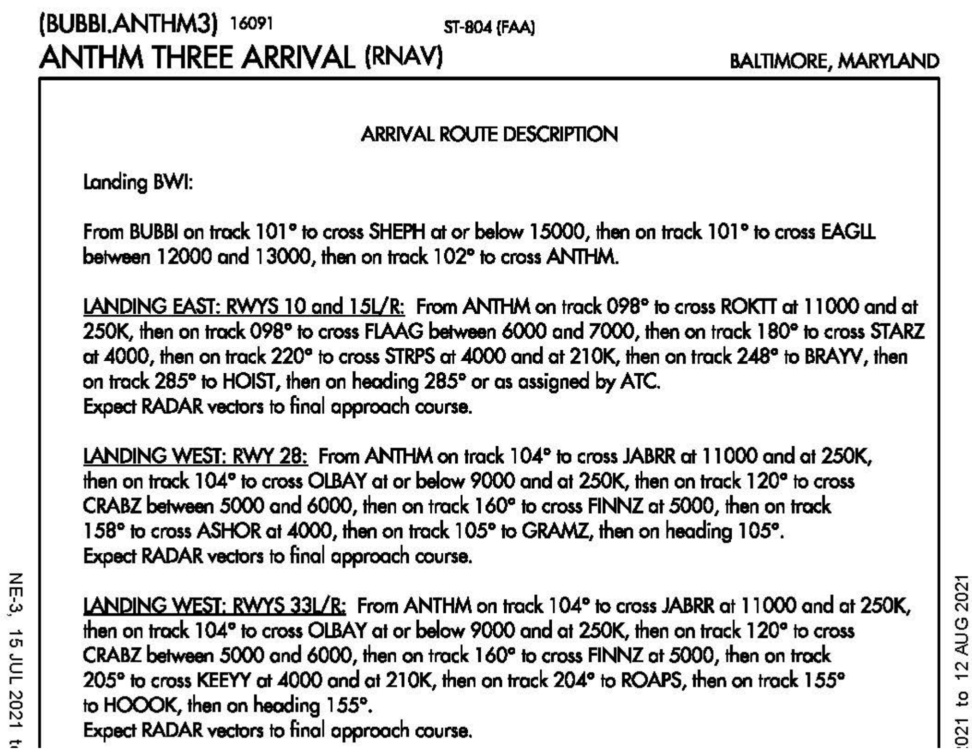


Figure 16. KBWI ANTHM THREE RNAV STAR runway transition graphic.



(BUBBI.ANTHM3) 16091 ST-804 (FAA)

ANTHM THREE ARRIVAL (RNAV) BALTIMORE, MARYLAND

ARRIVAL ROUTE DESCRIPTION

Landing BWI:

From BUBBI on track 101° to cross SHEPH at or below 15000, then on track 101° to cross EAGLL between 12000 and 13000, then on track 102° to cross ANTHM.

LANDING EAST: RWYS 10 and 15L/R: From ANTHM on track 098° to cross ROKTT at 11000 and at 250K, then on track 098° to cross FLAAG between 6000 and 7000, then on track 180° to cross STARZ at 4000, then on track 220° to cross STRPS at 4000 and at 210K, then on track 248° to BRAYV, then on track 285° to HOIST, then on heading 285° or as assigned by ATC.
Expect RADAR vectors to final approach course.

LANDING WEST: RWY 28: From ANTHM on track 104° to cross JABRR at 11000 and at 250K, then on track 104° to cross OLBAY at or below 9000 and at 250K, then on track 120° to cross CRABZ between 5000 and 6000, then on track 160° to cross FINNZ at 5000, then on track 158° to cross ASHOR at 4000, then on track 105° to GRAMZ, then on heading 105°.
Expect RADAR vectors to final approach course.

LANDING WEST: RWYS 33L/R: From ANTHM on track 104° to cross JABRR at 11000 and at 250K, then on track 104° to cross OLBAY at or below 9000 and at 250K, then on track 120° to cross CRABZ between 5000 and 6000, then on track 160° to cross FINNZ at 5000, then on track 205° to cross KEEYY at 4000 and at 210K, then on track 204° to ROAPS, then on track 155° to HOOOK, then on heading 155°.
Expect RADAR vectors to final approach course.

NE-3, 15 JUL 2021 t

021 to 12 AUG 2021

Figure 17. KBWI ANTHM THREE RNAV STAR text instructions for runway transitions.

There are different lateral paths that might be taken after reaching the STAR terminus (endpoint). If the end is a VM or FM leg, then some FMSs will stay on the last heading or track and show a route discontinuity after that, which means that the further path is not defined. The pilot must then resolve the discontinuity by selecting a runway/approach transition. However, turning on to the runway/approach transition requires an ATC clearance, so timing is important. The clearance must be received before the aircraft turns on to the runway/approach transition (i.e., feeder route).

Other FMSs treat a VM leg differently if there is an RNAV transition in the navigation database that begins at a point where the STAR terminates. In that situation, the FMS will automatically string together ("autostring") the STAR to the adjoining runway/approach transition, saving the pilot the step of resolving the discontinuity. This can be efficient but has the potential for the FMS to connect the paths when not intended by the pilot. For example, ATC might tell the pilot to connect to a different runway transition than the FMS would connect with the autostring function. In this case, the pilot must disconnect the automatically connected transition then select the assigned one, which could require several steps.

NAVCanada offers an interesting alternative way to design the connection from STARS to IAPs (NAVCanada, 2020). The concepts are explained to pilots in the Canadian AIM (Transport Canada AIM, Section 9.2.3.10, 2021). NAVCanada offers two types of STAR connections to IAPs, *open* and *closed*.

Closed STARs automatically join the final approach course with a straight-in entry. The closed STAR is a continuous path from the en route structure that ends at the FAF (known as the final approach course fix, FACF, in Canada). Normally, the inbound track from a closed STAR is within 90° of the final approach to the runway (Transport Canada AIM, Section 9.2.3.10, 2021). When the approach clearance is received, the pilot will fly the charted track, observing all published flight path constraints, intercept the final approach course, and continue with the straight-in approach to land.

Open STARs place the aircraft in position for a downwind entry that does *not* automatically join the final approach course. The aircraft continues along the downwind until ATC issues instructions on turning towards the runway (via radar vectors or published transition) and gives an approach clearance. If the approach clearance is not issued the aircraft must not turn toward the runway, even if it passes the expected entry to the runway transition; ATC will then issue vectors when ready. The lateral path of open STARs can be linked in the FMS to the lateral path of some runway/approach transitions, including transitions to ILS approaches. If there is a connection from the open STAR to an RNAV runway transition, the IAF (known as the Initial Approach Waypoint, IAWP, in Canada) will be published on both the STAR and the IAP charts. Such waypoints are known as the STAR/approach interface waypoint (NAVCanada, 2020).

Entering an approach requires an ATC clearance. The ATC procedures for issuing approach clearances are described in FAA JO 7110.65Z Section 4-8-1 (2021). ATC can issue vectors all the way from the end of a STAR to the final approach course, or they can issue a clearance for a feeder route (runway transition) from the end of a STAR. ATC can ask the aircraft to join an RNAV transition at the IAF, the IF, or any waypoint in between. Some MARS applications propose that ATC would issue vectors then rejoin the aircraft to an RNAV transition. In any case, pilots know that the clearance for an approach is different from knowing what approach path they will get. While pilots may "expect" a particular type of connection (based on ATIS, or a chart note, or a prior controller's statement), they are not allowed to fly the runway/approach transition without a clearance, and that plan could change relatively late.

7.2 Industry Discussions

As mentioned earlier, the PARC PCPSI working group has formed a subgroup to discuss operational issues related to arrival-approach connections. The Arrival-to-Approach Connections (AAC) subgroup began meeting in January 2021 after Volpe Center submitted the topic for consideration in August 2020. Our initial issue submission pointed out a variety of previous presentations that all touched upon this common theme, including a presentation on MARS from May 2020. The goal for the discussion was to make recommendations to support the development of new connections for MARS and to address ongoing issues with existing connections. The recommendations may be for FAA and/or operators. Our initial questions were:

- What are some existing types of connections between arrivals and approaches in the United States and where are they used?
- What are pilots taught about how to handle the different types of connections between arrivals and approaches?
- What types of errors might pilots make when connecting from arrivals to approaches?
- What factors contribute to these potential pilot errors (e.g., aircraft/equipment, airport environment, or training)?
- How can we understand and organize the variety of connections that exist or are proposed?

These issues are related to PBN operations and may have implications for ATC phraseology as well as chart design. The objective of the AAC subgroup is to address issues related to operational deficiencies that have been identified with approach clearances and execution related to arrivals connected to PBN and conventional approach procedures.

The AAC subgroup first identified several tasks. These were to:

- Review current criteria [for IFP design], FAA and pilot guidance/training used to facilitate arrival to approach connectivity
- Identify the different types of arrival to approach connections
- Identify issues/problems with current methods
- Identify alternatives that will address issues/problems with current methods
- Review/consider international documentation related to arrival to approach connectivity
- Discuss operational concepts for missed approaches and departures procedures associated with MARS operations.

After reviewing background material (some of which was presented in Section 7.1), the group developed a list of specific topics and is working through these.

- ATC approach clearances
  - "Distance/time rule"
  - How far or long before the IAF is an approach clearance required?
- Aeronautical charts
  - Should the IAF be shown on the STAR and/or should the STAR be listed on the IAP?
  - What should be the content of the text route description box? Is it needed or not? What should be the standard language?
- ATIS language
  - What are the standards for EoR to tell the pilot what runway/transition to expect?
  - What should be the standards for other ATC operations in progress, such as MARS?

- ATC phraseology
  - Language should be standardized. Use the existing phraseology or create something new?
- Pilot education
  - What to load in the FMS and when?
  - What to say to ATC and how to say it?
  - What to do after an expect clearance or clearance that is canceled?
- FMS standardization (related to education)
- Are there aircraft-specific issues preventing standardization?
- IFP Designs
  - Connection waypoint attributes (fly-over vs. fly-by; altitude and/or speed constraints)
- MARS
  - Does the aircraft need to be on centerline or within the RNP value to be 'established' on the IFP?

8. Recommendations for MARS

This section presents recommendations for MARS based on all the components of this project. Some of the recommendations grew out of what we learned in the pilot listening sessions. Others came from our literature review, preliminary work on airspace complexity, and our evaluation of a notional MARS application. We also considered the industry discussions and operational complexity issues associated with flying IFP connections.

Here we present just the recommendations in brief. We refer the reader to other sections of the report for supporting evidence for the recommendations. Section 8.1 has the site-specific recommendations. Section 8.2 has recommendations related to IFP complexity. Section 8.3 has general recommendations.

8.1 Site-Related Recommendations

These site-specific considerations apply to each site where MARS will be implemented.

- **Consider local characteristics such as the mix of traffic, typical weather patterns, and pre-existing challenging flight paths.** Section 4.4 (on the pilot listening sessions for NY) provides examples of how these characteristics can impact flightcrew tasks and workload. We elaborate on our recommendations for each local characteristic below.
  - *Traffic mix.* Understanding the local traffic diversity (e.g., domestic or international routes, airline or corporate operators, variation in aircraft equipment) will provide insights into the unique needs and capabilities of different MARS users. We recommend obtaining input from all types of local operators to ensure that MARS works for everyone, thereby maximizing MARS safety and efficiency benefits.
  - *Weather patterns.* Typical weather in the region will impact when MARS can be used at a particular site. Regions like NY may be more impacted than regions where the weather is generally fair and consistent (e.g., Southern California). With reduced separation there may be less room for flight path deviations due to weather. We recommend considering how MARS will operate under dynamic weather conditions that are typical at each proposed MARS site. For example, how quickly can ATC switch between MARS and non-MARS operations during pop-up thunderstorms?

- *Pre-existing (challenging) flight paths. We recommend looking for opportunities to build* on or improve pre-existing IFPs when designing MARS applications. For example, MARS applications might codify unpublished routes, speeds, and altitudes that ATC commonly uses. This should ease pilot workload and convey expectations to unfamiliar pilots. New MARS applications might also reduce or eliminate the need for pre-existing IFPs that are difficult to fly.

- **Evaluate airspace complexity for pilots at potential MARS sites to understand local challenges.**

  The types and relative frequency of external threats related to airspace complexity for pilots may be different from one region to another. We recommend developing an airspace complexity profile for each MARS site to determine how MARS applications might be designed to lessen potential negative impacts of local airspace complexity threats. We defined a working construct of airspace complexity for pilots in Section 3.3 and demonstrated a way to develop an airspace complexity profile from ASRS events in Section 4.3.

8.2 Refinement of Proposed MARS Applications

- **Assess proposed MARS applications from the pilot's point of view.**

  We recommend doing a conceptual flythrough of each proposed MARS application from a pilot's perspective to identify any open questions about how it might work. Doing so will help to identify and mitigate potential areas of error or confusion for pilots. We demonstrated a method for assessing a notional MARS application in Section 6.3. We incorporated findings from past research on IFP complexity when evaluating this application (Chandra & Markunas, 2017).

- **Review findings from previous research on IFP complexity.**

  Past research on IFP complexity offers a number of considerations for IFP and chart design to reduce pilot confusion when flying IFPs (Chandra & Markunas, 2017). We provide example recommendations from this work in Section 6.3. We recommend that these findings be considered when developing new IFP designs for MARS applications. One way to do this is by applying the findings to a conceptual flythrough, as noted above. Results from the study may also be useful in providing context for the recommendations related to IFP designs. For example, the study describes how pilots review and manage speed and altitude constraints, and how different aircraft equipment affects workload of managing autoflight systems to meet PBN standards. This can be helpful for anticipating pilot workload associated with MARS IFPs.

8.3 General Recommendations

- **Consider whether (and what) changes to pilot-ATC communications might be anticipated with MARS.**

  Increased use of PBN may change the frequency and content of communications between pilots and ATC (see Section 4.4 for examples of pilot-ATC communication issues where PBN is used infrequently). On one hand, PBN may reduce the number of communications because pilots will follow charted IFPs with fewer real-time instructions from ATC. On the other hand, pilots may need to query ATC if they have questions about new IFPs or negotiate with ATC if they have difficulty meeting IFP constraints. With reduced separation there may also be less tolerance for delayed communications (e.g., due to congested frequencies) or misunderstandings (e.g., due to non-standard or confusing phraseology). We recommend considering potential MARS impacts to pilot-ATC communication. Would new guidance or technologies be needed? For example, could CPDLC be in place concurrently with or in advance of MARS implementation to reduce radio chatter and increase standardization?

- **Continue efforts to understand and address operational complexity and IFP connections.**

  Section 7 discussed how arrival-to-approach connections are an area of risk for pilots in real-world operational environments. The PCPSI AAC subgroup is continuing its effort to understand and address pilot and ATC issues regarding arrival-approach connections. The AAC is considering MARS operations specifically and may generate their own recommendations for MARS IFP connections. We recommend that the FAA continue its coordination with the AAC to anticipate potential operational issues with MARS applications.

- **Identify ways to demonstrate MARS benefits and spread them across users.**

  The FAA may want to use a phased implementation approach for MARS, in which change is managed incrementally to build users' confidence and familiarity with the operation. Section 3.2 provides examples of how this approach was successful for EoR. If MARS uses a phased approach, we recommend identifying situations where pilots and ATC can practice MARS operations under relatively low-risk conditions. We also recommend that anticipated benefits and costs be spread across airspace users (e.g., different airports or operator types) so that no one group experiences more benefits or costs than another.

- **Consider pilot education needs.**

  We recommend considering what information pilots need to know about MARS and how to disseminate this information. Some have pointed out that, on one hand, pilots will simply fly the IFPs as they normally should, regardless of whether the IFPs are part of a MARS application. Pilots are not normally aware of the methods that ATC uses to maintain separation. These viewpoints promote the notion that pilots do not need to be educated about MARS.

  On the other hand, we know from the listening sessions that pilots had several questions about flight deck operations under the MARS concept. We identified some of these general questions in Section 4.4.3.4. Pilots want to understand the MARS concept, regardless of whether it is in use. The PCPSI AAC subgroup is also examining how to educate pilots about IFP connections that may be used for MARS (see Section 7.2). For example, they are considering what pilots should load into the FMS and when, what pilots need to say to ATC and how, and what pilots should do after an "expect" clearance or a clearance that is canceled. Also, being aware that MARS operations are in effect may remind pilots that they must manage their flight path exactly as specified and report any deviations immediately to ATC.

9. Summary and Conclusions

This project addressed multiple research needs related to flight deck human factors perspectives on the NextGen MARS concept. We completed several research tasks including a literature review, exploration of the concept of airspace complexity for pilots, collection and analysis of data about flight operations in the NY metropolitan region as a case study, assessment of one proposed application of MARS for NY, and an exploration of pilot resilient behaviors. Some of the work was conceptual, some was based upon existing data (ASRS events), and some was based on new data from the pilot listening sessions. We also used our knowledge of PBN IFPs to assess an example MARS application and developed a set of considerations and recommendations for work to help mature the MARS concept.

The MARS concept has the potential to achieve multiple goals at locations such as NY. It would encourage the development and use of PBN IFPs, which could increase the safety and efficiency of flight operations. However, NY is a challenging area for PBN IFPs. Introducing PBN at NY will address some challenges and may create a few familiar ones. The transition to PBN will need to consider lessons learned from previous efforts to implement PBN. It should also be coordinated in a way such that benefits are noticed by all users at each stage of implementation.

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Appendix A: Airspace Complexity

Environment

Threat	Example Observable Parameters
Weather (of all types) that requires attention	Pilot seeks more information about weather Pilot explores options for handling weather Low visibility or nighttime conditions Fast-changing weather Intense weather Unpredicted weather
(High) Traffic	Number of operations in airspace or at airport Mix of different aircraft types Mix of VFR and IFR traffic Go-arounds due to traffic conflict TCAS RA or TA Wake turbulence encounter

Airspace

Threat	Example Observable Parameters
High-density Terminal Area Airspace Design	Multiple IFPs Multiple nearby busy airports Multiple runway transitions VFR corridors
(Large) amount of information to brief/know, impacting pilot tasks	Visual density of chart(s) Number of available charts Existence of Attention All Users Page Existence of airport bulletin or other specialized training Difficulty interpreting charts Difficulty accessing correct chart Charted Visual procedures (with a lot of elements crews need to be aware of)
(Complex) Design of IFPs	Number of transitions Number of constraints Prohibited and special use areas to avoid Terrain/obstacles to avoid Waypoint names hard to use Energy mismatch between route segments Ambiguity (unclear what path to fly)

ATC Interactions

Threat	Example Observable Parameters
Time-pressure	Timing of clearance amendment Timing of runway change Speed or urgency of communications Difficulty reaching ATC and getting responses (includes not hearing calls initiated by ATC if frequency congestion is the issue)
(Lack of) clarity of communication	Confusing phraseology Confusing/misunderstood content Read-back or hear-back errors Crew not following ATC instructions Internal crew discussion about the meaning Complex clearances, e.g., clearances with conditional statements such as "at this time" or "at this altitude"
Changing instructions	Clearance amendments Runway change Unexpected vectors Published IFP modified by ATC Include changes to expected runway announced via updated ATIS
Unpublished restrictions assigned	ATC assigns a speed or altitude restriction that is not on a published IFP (e.g., speed assigned on a visual approach)

Flight Deck Equipment

Threat	Example Observable Parameters
Time-pressured set up or configuration	*See time-pressured ATC interventions* Could lead to an unstable approach Errors in aircraft configuration or speed management (e.g., flaps, slats, speed brakes)
Unexpected behavior of automated system	Extra tasks to sort out options and behavior Clearing an unexpected route discontinuity Deleting a route (segment) to set up a new connection Equipment-specific extra steps or "gotchas"
Aircraft performance requires attention	Difficulty slowing down while descending, use of speed brakes or early flaps Difficulty meeting a speed or altitude constraint

Appendix B: ASRS Coding Rubric

This is the coding rubric used to review each of the ASRS events in this report. The text in bold surrounded by brackets is explanatory. It was not in the final event coding.

ACN # <Enter number here>

Synopsis

- <Fill this out last>

☐ PBN-related issues
☐ FMS in use **<Check this if the crew was using the FMS at all, not just if they had FMS problems.>**
☐ Hand-flying involved
☐ Wind issues
☐ Part 121
☐ Part 91
☐ Mentions resilient behaviors **<Put details under the Resilience bullet later>**

Location

☐ JFK ☐ EWR ☐ LGA ☐ TEB

Pre-Approach Navigation

☐ STAR ☐ Vectors ☐ n/a

If STAR, full name and whether it is RNAV/PBN: **<Enter STAR info here>**

Approach Navigation

☐ ILS ☐ Visual ☐ RNAV (RNP) ☐ RNAV (GPS) ☐ Varied ☐ Other or n/a

Which runway(s)? **<Enter runway info here>**

Segment where main issue occurred

☐ Joining approach transition

☐ On approach transition, inside the IAF

☐ On approach transition, inside the IF

☐ Joining inbound course

☐ Along inbound course

☐ On downwind

☐ Departure **<Enter runway here, if known>**

Type of Connection

☐ Vectors to Downwind ☐ Vector to inbound course ☐ RNAV transition ☐ n/a

Reporter

<If there is more than one narrative, include the narrative number next to the type of reporter as shown.>

☐ Captain **(1)** ☐ First Officer **(2)** ☐ Pilot Flying **(1)** ☐ Pilot Monitoring **(2)** ☐ ATC **<Add type, optional>**

Outcome

☐ Lateral deviation
☐ Vertical deviation
☐ Go-around
☐ Unstable approach
☐ Speed management
☐ Vectors
☐ TCAS RA
☐ TCAS TA
☐ Loss of separation
☐ Misconfiguration (e.g. flaps, slats, speed brakes, landing gear)
☐ Terrain Alert
☐ Other, describe: **<Explain here>**

Threat

<Definitions for these threats in Appendix A>

Environment

☐ Weather (of all types) that requires attention
☐ (High) Traffic

Airspace

☐ High-density Terminal Area Airspace Design
☐ (Large) amount of information to brief/know, impacting pilot tasks
☐ (Complex) Design of IFPs

ATC Interactions

☐ Time-pressure
☐ (Lack of) clarity of communication
☐ Changing instructions
☐ Unpublished restrictions assigned

Flight Deck Equipment

< This refers to all flight deck equipment, not just the FMS.>

☐ Time-pressured set up or configuration
☐ Unexpected behavior of automated system
☐ Aircraft performance requires attention

Context

-

Resilient Behaviors

- <These are positive pilot actions and behaviors.>

Explanation of Coding

-

Other Operational Complexity Factors
<These are operational complexity factors that were not already covered under “threats.”>

Factors	Notes, New Examples, Details
Environment-extras ☐ Terrain ☐ Man-made structures ☐ Recent design changes/redesign to airspace ☐ Nighttime	

Flightcrew Factors
☐ Lack of familiarity
    ☐ Terrain
    ☐ Local area
    ☐ Local IFPs
☐ Lack of knowledge/training
    ☐ IFP designs
    ☐ Aircraft autoflight systems
☐ Confusion related to FPM
☐ Lack of flight path awareness
☐ Time pressure related to FPM
☐ CRM
☐ Decision making
☐ Distraction
☐ Crew physical condition
☐ Time pressure unrelated to FPM
☐ Non-normal situation unrelated to FPM
☐ Decision making unrelated to FPM
☐ Confusion unrelated to FPM
☐ Generic crew error
	<These are neutral or negative pilot actions and behaviors.>

Operator ☐ Dispatch ☐ Clarity of pilot roles ☐ Clarity of SOPs	
ATC Issues Only ☐ Aircraft sequencing ☐ Internal ATC coordination ☐ Generic ATC error	

Appendix C: Pilot Listening Session Script

Introduction

This study, titled "Line Pilot Input on Flight Operations at High-Density Airports," is being conducted by the Volpe National Transportation Systems Center, United States Department of Transportation. The research is directed by Andrea Sparko (617-494-3363) and Dr. Divya Chandra (617-494-3882).

The study is funded by the FAA NextGen Human Factors Division as part of the Next Generation Air Transportation System (NextGen) program.

Purpose

The main purpose of this study is to explore flight deck issues related to flying under a proposed concept for instrument flight procedures. This concept would allow aircraft flying along specially designed pairs of PBN instrument flight procedures (arrivals, departures, and approaches) to safely fly in areas of reduced separation, which could be less than 3 NM. The FAA is considering whether and how the concept could be developed for high-density airspaces such as New York and Southern California to improve traffic flows and reduce conflicts between close-by airports.

Plan

We would like to understand your experiences and observations about flying in high-density airspaces through a virtual conversation. We anticipate taking an hour of your time. The conversation will cover your experience flying in New York, your awareness of other aircraft traffic, and any other thoughts you have about operating at New York, including questions about PBN at NY.

Your participation in this study is completely voluntary and confidential. No individual names or identities will be recorded with any data or released in any reports. Only arbitrary numbers are used to identify pilots who provide data.

The researchers will take notes during the conversation. These notes will be kept anonymous. The report will not link information about individuals' identities with specific discussion points. It will only report findings such that the identity of the individuals cannot be readily ascertained. No audio or video recording will be used.

You may withdraw your participation at any time without penalty. You may contact either of the researchers listed above if you have any further questions.

Statement of Consent

Could you please confirm that you understand the purpose and plan for the discussion, and that you freely consent to participate in this study under the conditions described?

Flight Experience

Tell us about your flight experience.

- How long have been flying for your current company?
- What types of operations do you fly most often?
- What type of aircraft do you fly most often?
- Do you operate in the NY region? If not, what are the most traffic-dense regions you fly regularly?
- Where are you based?

<u>Notes</u>

Flight Operations at New York (NY) Area Airports

1. **Tell us what it is like to fly in the NY area.**

- What makes NY similar or different from other places you fly?
- Compare the "unpredictability" of operations at NY with other places you fly.

<u>Notes</u>

2. **Tell us about your interactions with NY ATC.**

- How often do you receive revised clearances from ATC (either route amendments or revised constraints) relative to other locations?
- How responsive is NY ATC to pilot requests (relative to other locations)?
- What are the most common problems that occur in the NY area for pilots? What do you see as the source of these issues? (Density of traffic, ATC clearances, familiarity with area/operations, other?)

<u>Notes</u>

Traffic Awareness in the Vicinity of Multiple Airports

1. **Tell us about how aware you are of other traffic and flight operations around New York.**

- Is knowing about traffic at other airports useful to you?
- How do you find out what is going on at nearby airports?
    - Do you use your flight deck traffic display to monitor nearby aircraft? How so?
    - What do you know about the traffic at other nearby airports?
    - Would you know what runway configurations are in use at nearby airports?

<u>Notes</u>

2. **What risks (if any) do you anticipate regarding reduced separation on pairs of PBN IFPs?**

To review, a proposed concept would allow aircraft established on different IFPs, such as approaches, arrivals, or departures, to fly closer than standard radar separation (i.e., less than 3 NM apart) for a portion of the IFP.

- How would your operation be affected?
- What would pilots need to be aware of?
- What if the nearby aircraft were flying to/from a different airport than you?
- Would you feel comfortable flying in reduced separation in a mixed-traffic environment (e.g., general aviation and air transport operations, or IFR and VFR operations?
- Under what conditions might you not be comfortable with reduced separation even when on different IFPs?

Notes

General Wrap-Up: Operations at NY/TEB

1. What improvements to NY/TEB airspace and flight procedures would you suggest?

Notes

2. What risks (if any) do you anticipate with the implementation of PBN in the NY area

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