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AIRSPACE COMPLEXITY FOR PILOTS OPERATING IN HIGH-DENSITY TERMINAL AIRSPACE: NEW YORK CASE STUDY

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Performance-based navigation (PBN) has been implemented in the redesign of terminal airspace across the National Airspace System (NAS). However, some locations, such as the New York metro area (NY), have not adopted PBN widely. Modernizing flight operations at high-density terminal airspace like NY is challenging, but also has the potential for significant operational benefits if successful. This research aims to understand the flight deck perspective on flying in high-density terminal airspace. We analyzed 73 events from the Aviation Safety Reporting System (ASRS) to assess flight operations at four major NY airports before COVID-19. We defined and explored the concept of airspace complexity for pilots operating in the terminal airspace. Our concept is comprised of four types of external threats related to flight path management: air traffic control interactions, autoflight systems on the flight deck, airspace and flight procedures, and environment. Our findings paint a picture of flight operations in NY.

The Federal Aviation Administration (FAA) has made significant progress modernizing the National Airspace System (NAS) through new technologies and procedures for pilots and controllers under the Next Generation Air Transportation System (NextGen) program. Performance-based navigation (PBN) is a cornerstone of NextGen. It is based upon Area Navigation (RNAV) and Required Navigation Performance (RNP), which allow aircraft to fly more precise lateral routes using satellite navigation and/or other aircraft navigation systems. NextGen leverages PBN for the design of new instrument flight procedures (IFPs) that define routes in and out of terminal airspace, including arrival, departure, and approach procedures.

A PBN NAS strategy report describes the benefits of a PBN-centric NAS (FAA, 2016). One benefit is an improvement in system-wide efficiency by increasing the homogeneity of NAS operations across the country. Another benefit is that NextGen paves the way toward future air traffic management capabilities. And, a PBN-centric NAS allows stakeholders to take advantage of investments in advanced navigation capabilities. In order to realize the benefits of NextGen, however, it is important to increase the utilization of PBN procedures. One of the areas that has been slow to adopt PBN is the New York metro region (NY), which has four busy airports in close proximity: John F Kennedy International (KJFK), La Guardia (KLGA), Newark International (KEWR), and Teterboro (KTEB). This is high-density terminal airspace, with multiple airports and a large number of flights. Here we explore what makes NY a challenging area from the pilot's perspective.

Background

NY has a complex terminal airspace, in part, because of the close physical proximity of its major airports. KJFK is 18 miles east of KTEB and KEWR, and just 9 miles southeast of KLGA. Their relative locations and runway configurations constrain the arrival, departure, and approach procedures that can be assigned to aircraft while keeping them safely separated. In addition, their close 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 visual meteorological conditions when arrival and departure rates peak. Pilots familiar with the area told us that prior experience with NY Air Traffic Control (ATC) and airspace procedures makes the flight operations manageable.

Our concept of terminal airspace complexity for pilots was informed by two research strands. The first strand was done to support the Free Flight concept (RTCA, 1995). The goal of Free Flight was to allow pilots more freedom to select optimal flight routes with the ability to self-separate from other air traffic under some conditions. Free Flight operations were focused on enroute airspace, where flows are more structured and traffic density is lower. Free Flight spurred research on airspace complexity from a controller perspective because it was a way to understand "the effect of changing airspace configurations and traffic patterns on the workload of air traffic controllers" (Sridhar et al., 1998). A key parameter of interest was "dynamic density," an idea first mentioned in the 1995 RTCA report. Dynamic density takes into account not just the number of aircraft, but their relative positions and how those positions (and geometries) are changing over time (cf. Kopardekar, et al., 2007; Histon, et al., 2002).

Riley and others studied airspace complexity for pilots for the task of strategic conflict avoidance (Riley, et al., 2003; Riley, et al., 2004). Riley et al. (2004) point out 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, restricted airspace, and terrain, especially when fast-changing weather could constrain future aircraft maneuvering.

The second research strand we built upon was work on PBN flight operations, their associated charting, and design of IFPs. Chandra and Markunas (2017) studied line pilot perspectives on the complexity of IFPs, aeronautical charts, and flight path management. Complexity associated with the design of individual IFPs includes factors such as the energy profile, altitude and speed constraints, transitions (i.e., branches) in the route, restricted airspace, and even explanatory text notes.

Chandra & Markunas (2017) also defined five sources of "operational complexity," which occurs in normal operations. These are: ATC interventions, aircraft equipment and performance, environment, crew, and operator factors. Operational complexity factors vary day to day in real-time (e.g., ATC clearance amendments). Controllers and pilots work together to resolve operational issues because these cannot be mitigated in advance through IFP design. Chandra, et al. (2020) found that although PBN can complicate the situation, operational complexity exists even without PBN. Environment factors within operational complexity include terrain, traffic, weather and prohibited airspace; these same factors were mentioned by Riley et al. (2004) in terms of airspace complexity for pilots.

IFP design is distinct from operational complexity, but it is related to airspace design and traffic flows. Arrival, departure, and approach IFPs that pilots expect to fly are proposed in their flight plans and assigned via ATC clearances. Published IFPs are selectable within the aircraft's navigation database. The terminal airspace contains multiple published IFPs that may cross in three-dimensions.

Airspace Complexity for Pilots

Our concept of airspace complexity for pilots includes four types of factors: air traffic control interactions, autoflight systems on the flight deck, airspace design and IFPs, and environment. We chose to focus on external factors that affect the pilot's ability to manage their flight path under normal operating conditions in the terminal airspace. We do not consider emergencies or non-normal conditions. We also excluded internal pilot factors such as fatigue and training. The concept does consider the entire airspace design, not just a single IFP.

This concept of airspace complexity for pilots combines aspects of the concept of airspace complexity for controllers (e.g., traffic and airspace geometry) with IFP design factors and operational complexity factors. As with airspace complexity for controllers, we expect that airspace complexity for pilots will vary in time. We also expect that airspace complexity for pilots will vary by airspace, traffic density, and traffic geometries. Airspace complexity for pilots is also impacted by the capabilities of the aircraft autoflight systems. This is a difference between the pilot and controller views of airspace complexity; controllers are generally unaware of the autoflight system capabilities. The design of IFPs, and use of PBN, is factored into this concept through the airspace design factors.

Method

We reviewed 100 events from the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) that occurred in the NY terminal area between October and December 2019 (before the impacts of COVID-19). From these, we selected a dataset 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.

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. 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.

We developed a coding rubric to classify each event. The rubric included a synopsis of the event, factual information (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 pilots hand-flew during the event or used the flight management system (FMS). Two researchers reviewed each event and resolved any discrepancies. Table 1 lists the threats we recorded, which were elements from our concept of airspace complexity for pilots.

Table 1.
Threats related to Airspace Complexity for Pilots in High-Density Terminal Airspace.

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

Results and Discussion

Of the 73 events, 31 occurred at KEWR, 29 at KLGA, 8 at KTEB, and 5 at KJFK. Thirteen events occurred on departure, 16 on arrival, 20 on approach, and 24 occurred while connecting from the arrival to the approach. Most of the events (58, or 79%) were reported by a Part 121 operator (scheduled air carrier). There was one event each from a Part 135 (charter) and Part 91 (general aviation) 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 quickly resolve a traffic conflict. Thirteen events (18%) involved wind-related issues.

The most common outcomes (occurring in at least 10 events each) were Vertical Deviations, Unstable Approaches, Traffic Alert and Collision Avoidance System (TCAS) Resolution Advisories (RA), 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). Speed Management Issues, Misconfigurations, Go-Arounds, Terrain Alerts, Vectors, TCAS Traffic Advisories, and Losses of Separation each occurred in fewer than 10 events. We also identified 24 “Other” outcomes. Examples of these included exceeding 250 knots below 10,000 feet (which is generally not authorized under federal regulations), landing without a clearance, and losing sight of the runway while flying a charted visual approach. KLGA has two charted visual approaches, the River visual and the Expressway visual, which may be difficult for pilots to fly if they are not familiar. These charted visuals are generally hand-flown, which can be especially challenging with crosswinds.

Figure 1 shows how often each threat occurred as a percent of the 73 events in the dataset. Note that a single event might have multiple associated threats. 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, 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, atypically, for a visual approach.

Airspace threats were present in just 11 of the 73 NY events (15%). Interestingly, Complex Design of IFPs was mentioned by pilots in only 4% of the NY reports. In contrast, Chandra et al. (2020), found that Complex Design of IFPs was coded in 35% of 148 events analyzed at locations that had PBN IFPs. It appears that the pilots are more aware of complex IFP designs when PBN is implemented. At NY, the tactical nature of ATC may make the airspace complexity less visible to pilots. The downside of this tactical approach is that it creates time-pressure, which then creates 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 recorded 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. With four major airports, there is more air traffic at NY than at 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), 32% of 148 events, was similar in these results (30%).

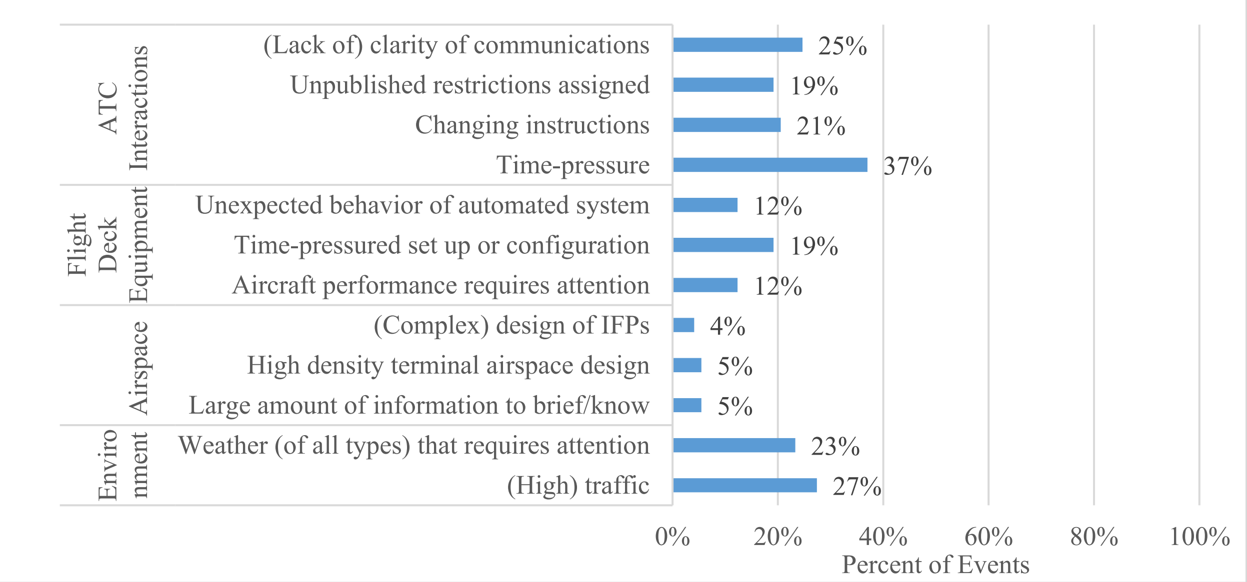

Figure 1. Prevalence of threats related to airspace complexity for pilots in the dataset.

Summary and Next Steps

We explored the pilot perspective on the challenges of operating in a high-density terminal airspace, using NY as a case study. ATC Interactions are high in this airspace confirming that flight operations are uniquely demanding at NY. PBN is not used often at NY, and it appears that the tactical nature of ATC at NY makes the structure of the airspace and procedures less visible to pilots. Out next planned step is to compare these findings from ASRS data with data from discussions with professional pilots who operate in NY. Discussions with pilots may give us further insights into the challenges of flying in NY, and of the potential impacts of greater adoption of PBN IFPs.

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