Analysis of Safety Reports Involving Area Navigation and Required Navigation Performance Procedures

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ABSTRACT

In order to achieve potential operational and safety benefits enabled by Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures it is important to monitor emerging issues in their initial implementation. Reports from the Aviation Safety Reporting System (ASRS) were reviewed to identify operational issues related to RNAV and RNP procedures. This review is part of a broader effort to understand emerging human factors issues for performance based navigation. A total of 285 relevant reports filed between January 2004 and April 2009 were identified and analyzed. For departure procedures, the majority of reports mention heading or track deviations, which are classified as "lateral" issues. For arrival and approach procedures, the majority of reports mention altitude deviations, which are classified as "vertical" issues. The track and heading issues were often associated with dropped transition waypoints in the Flight Management System (FMS). Altitude deviations during arrival and approach procedures were mainly associated with Air Traffic Control (ATC) "descend via" phraseology. The analysis shows that RNAV and RNP procedure issues are integrated with ATC operations, FMS, and procedure design issues.

Keywords

Aviation Safety Reporting System, ASRS, RNAV, RNP, SIDs, STARs, IAPs, Performance Based Navigation, PBN

INTRODUCTION AND MOTIVATION

The Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) are transitioning to performance based navigation airspace. As a result, more Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures are being developed (MITRE CAASD, 2010). RNAV procedures allow the aircraft to fly directly between points in space without relying on ground-based navigation aids. RNP procedures meet specific requirements for position determination and track conformance, allowing the aircraft to fly more precise paths. RNAV and RNP procedures offer operators new levels of flexibility to negotiate terrain, airspace, and environmental considerations, and offer significant safety improvements. Operators see these benefits, and are pushing to develop more of these procedures. However, there are human factors concerns because RNAV and RNP procedures can result in paths that are complex to fly and typically require the assistance of a Flight Management Computer (FMC) to negotiate precise speed, altitude, and lateral path constraints. A list of related human factors issues was collected and summarized by Barhydt and Adams in a comprehensive research report (2006a). Separately, Barhydt and Adams (2006b) reported on an exploratory study using the Aviation Safety Reporting System (ASRS) database to identify 124 reports filed between 2000 and mid-2005 related to RNAV and RNP departure and arrival procedures at seven specific airports.

Barhydt and Adams were the first research team to systematically examine human factors issues related to RNAV RNP procedures. They broadly categorized key issues as being related to air traffic operations, pilot interpretation of procedures, and procedure design challenges with aircraft automation and charting. The research presented in this paper is part of a larger effort to build upon the work of Barhydt and Adams to understand emerging human factors issues with RNAV and RNP procedures related to procedure design and to understand charting issues for RNAV/RNP procedures in particular.

The goal of this review of events from the ASRS database is twofold. First, we are interested in knowing what performance issues related to procedure design and charting have been documented. Second we are interested in updating the analysis done by Barhydt and Adams by reviewing more current events and documenting human-performance issues.

AVIATION SAFETY REPORTING SYSTEM (ASRS) BACKGROUND

Safety reports of interest were identified from the public Aviation Safety Reporting System (ASRS) database managed by the National Aeronautics and Space Administration (NASA). The database contains voluntary self-reported descriptions of aviation safety events and can be searched in a flexible, customizable way. The outcomes and anomalies found in the ASRS reports are typically an actual violation or a "near violation" (i.e., a violation that almost occurred) of a requirement (e.g., an altitude clearance, or published heading for a departure or arrival procedure). Filing a voluntary ASRS

report grants the reporter a level of immunity for the violation as detailed in AC 00-46D (FAA, 1997).

There are limitations to the data contained in ASRS reports, which are described online (http://asrs.arc.nasa.gov/). The public database contains only a subset of the reports submitted for processing, so the frequency of events does not represent the total population of events. Because of the self-reporting nature of ASRS, reports may contain subjective biases. Reporters include air traffic controllers, pilots, and other crewmembers.

METHOD

The following fields were specified in order to identify relevant reports: Date of Incident, Keyword, Event Anomaly, and Flight Phase. The criteria used for these fields are listed in Table 1 below. A total of 2104 reports were extracted based on these search criteria. However, this set contained numerous cases that did not involve RNAV/RNP procedures because of the way the search query was constructed; these cases were discarded manually, yielding a total of 285 relevant reports for analysis.

The final set of relevant ASRS reports was reviewed to identify human factors issues related to RNAV procedures. The reports were grouped based on the type of procedure involved for the analysis: Standard Instrument Departure (SID), Standard Terminal Arrival (STAR), and Instrument Approach Procedure (IAP). The subjective narrative was reviewed carefully in order to extract as much information as possible about the event.

Field	Filter Criteria
Date of Incident	Jan 2004 – Jan 2010
Keyword	RNAV, RNP, Chart, Approach, SID, STAR, DP, IAF, FAF
Event Anomaly	Airspace Violation, ATC issues, Conflict (airborne, NMAC), Deviation – Altitude, Deviation – Procedural, Deviation – Speed, Deviation – Track/Heading
Flight Phase	Takeoff, Initial climb, Climb, Descent, Initial Approach, Final Approach, Landing

Table 1. Criteria used to search the ASRS database.

Each ASRS report was reviewed independently by two researchers. The reviewers determined whether the flight deviation that occurred was in the Lateral, Vertical, or Speed domain(s). Lateral issues included deviations in track or heading. Vertical issues pertain to altitude deviations. Speed deviations are less common than altitude deviations because speed is typically only a constraint below 10,000 ft altitude. Reviewers could assign more than one domain to a given report if multiple deviations occurred.

The reviewers also iteratively created a list of recurring problems that contributed to the event. The first iteration of the list of issues included the four broad categories that were used by Barhydt and Adams (2006b): automation, air traffic control, airline operations, and procedure design. However, this categorization proved to be too general given the large number of cases in the data set (285). Therefore, more specific issues categories were constructed. For example, procedure design issues were subcategorized based on their relation to:

- Chart Format (e.g., single page, fold-out, multiple pages)
- Chart Density (large amount of information on the chart in a small space)
- Graphic (visual depiction of the procedure)
- Notes (confusion with text description or procedure notes)
- Complexity (difficult to fly, e.g., hard bank angles required)
- Waypoint Constraints (depiction of altitude and other constraints at the waypoint)
- Other (miscellaneous chart confusion, unable to categorize)

To complete the analysis, ratings between researchers were reconciled and recurring problems were tallied.

RESULTS AND DISCUSSION

Of the 285 reports identified in this review, 202 pertain to departures, 69 pertain to arrivals, and 14 pertain to instrument approaches. The bulk of reports (235, or 82%) were from Title 14 Code of Federal Regulations (CFR) Part 121 operators (scheduled airline carriers). Just two reports were from Title 14 CFR Part 135 (charter/air taxi) operators and 45 were from Title 14 CFR Part 91 (private) operators. Although we requested reports through 2010, the most recent event retrieved was from April 2009, likely because of the delay in processing reports for the public database.

A large number of the reports in our set (41%) were filed in 2006. This was, coincidentally, the same year that ASRS published its own brief analysis of the Dallas-Fort Worth RNAV departure procedures (NASA, 2006). Many of the reports in our data set (88) are from the Dallas-Fort Worth region as well. This pattern may mean that: (a) Dallas-Fort Worth is an especially problematic region, (b) the ASRS team may have preferentially processed reports of RNAV procedure issues from Dallas-Fort Worth in 2006, or, (c) both.

Overall Results

Figure 1 below shows the number of reports classified in terms of the flight deviation domain, by type of procedure. Of the 202 departure-related reports, 175 involved lateral deviations (87%). For arrival procedures and approach procedures, deviations in the vertical domain were more frequent. Thirty reports out of the 69 arrivals (43%) and 12 out of 14 (86%) approach procedure deviations were in the vertical domain. (Note that because a single event could be assigned multiple domains, the sum of cases shown in Figure 1 is greater than the total number of cases.)

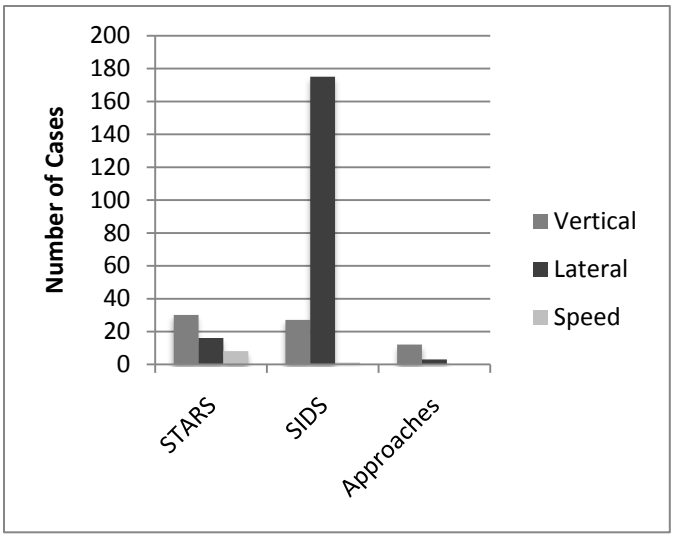

Figure 1. Deviations reported for each type of procedure categorized by Vertical, Lateral and Speed domain.

Figure 2 shows the number of cases for each chart and procedure design issue subcategory, as described earlier. A total of 59 cases of procedure design issues were identified. A single ASRS report could have generated more than one of these issues.

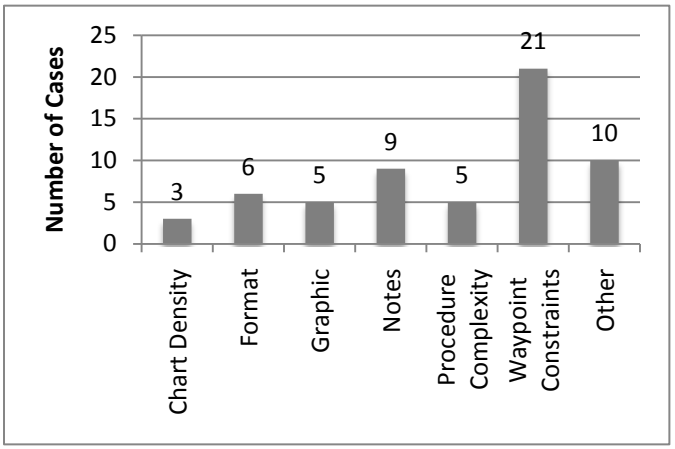

Figure 2. Frequency of procedure design issues across departures, arrivals, and approaches.

Waypoint Constraints were the most common problem across all procedures (21 reports). Examples include (a) confusion about the waypoint constraint and (b) not being able to conform to the depicted altitude or speed restriction. The second most common problem was with notes depicted in the procedure. In many of these cases, pilots reported being confused by the text descriptions of procedures that accompany the visual depiction. In six cases pilots reported issues with multi-page or fold-out chart formats. Less frequently observed issues related to procedure design include chart density, graphic depiction in charts, and procedure complexity.

Departure Procedure Issues

As mentioned earlier, the most frequent issue with departures was related to flight track/heading, that is, the lateral domain. Figure 3 shows a histogram of departure procedures issues. Four issues were categorized: *ATC Direct To and Resume*, *Climb Direct*, *Dropped Transition Waypoints*, and *Chart & Procedure Design*. A significant number of incidents related to departure procedures were reported by S80 crews, perhaps due to the high percentage of S80 operations out of Dallas-Fort Worth.

The most common issue was *Dropped Transition Waypoints* (30%). This refers to the fact that waypoints were sometimes dropped from the flight path in the Flight Management System (FMS) for unknown reasons. This issue was mentioned in the NASA Callback newsletter (NASA, 2006). The suggested solution was for pilots to check and recheck that all transition waypoints are in the system, especially if Air Traffic Control (ATC) changes a clearance.

Dropped Transition Waypoints may occur in combination with a change in the ATC clearance, such as the *Direct to and Resume*, a last minute change of departure runway, or a *Climb Direct* after departure. These clearances usually result in an off-path vector by ATC during climb out, with a subsequent resumption of the SID from a downstream waypoint. This problem was observed in 24 reports (11%).

During pre-flight, flight crews follow strict procedures in a relatively undistracted environment to check and recheck SID waypoints and waypoint constraints to ensure they match the chart. This task may not be easy if the chart has high information density or clutter. When the programmed route has to be modified in the high-workload dynamic environment present in the terminal area climb out, additional tasks including flying the aircraft, monitoring ATC and traffic, deciphering detailed charts, and other distractions can preclude a thorough recheck of the procedure. In particular the recheck of downstream waypoint constraints may be “hidden” in a subsequent Control Display Unit (CDU) page.

ATC may issue off-path vectoring for the purpose of shortening the path, separating traffic, or some other anticipated benefit. This however, must be balanced against the workload spike associated with in-flight FMS route modifications during dynamic phases of flight, which results in a higher risk of dropping waypoints and other errors. It may be worth investigating the human factors issues and cost/benefit tradeoffs of always requiring the procedures to be "flown as depicted", or evaluating whether procedure/depiction modification would facilitate re-acquisition of the programmed route at *downstream* waypoints, while minimizing trajectory errors.

Chart & Procedure Design issues, which were discussed earlier in the context of all procedures, are also shown in Figure 3 for departure procedures only. Approximately half of the overall *Chart & Procedure Design* issues occurred in departure procedures.

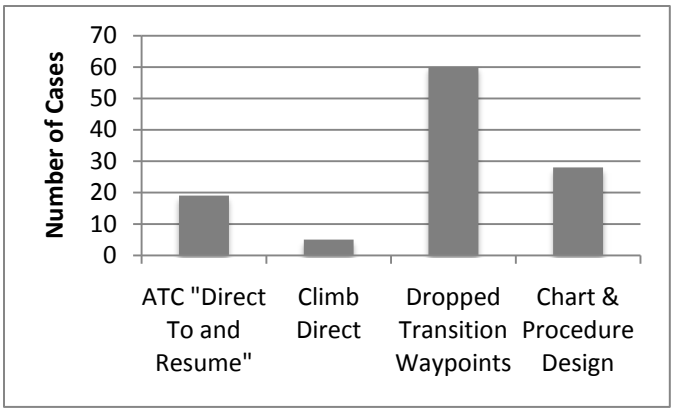

Figure 3. Departure procedure issues

Arrival Procedure Issues

As mentioned earlier, the most common problems with arrivals are related to altitude, that is, the vertical domain. Figure 4 shows a histogram of arrival procedure issues: *ATC "Descend Via" Clearance, Clearance Amendments & NOTAMS,* and *Chart & Procedure Design.*

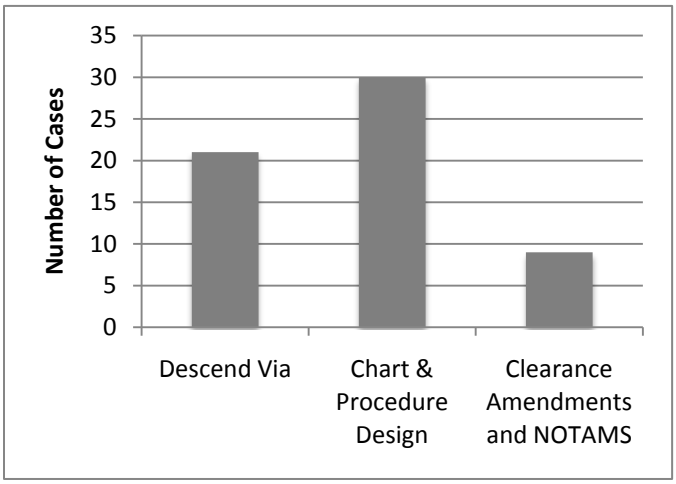

Figure 4. Arrival procedure issues

The most common issue was *Chart & Procedure Design* (43%). This issue was discussed in detail in the previous section. Approximately 50% of reports related to *Chart & Procedure Design* were reported for arrival procedures.

The second most common issue was *ATC "Descend Via" Clearances* (30%). This usually resulted in a pilot deviation for missed crossing restrictions when using ATC phraseology to "descend via" a procedure.

Pilots were confused by the "descend via" phraseology in several reports. As one pilot wrote:

> *"In talking with many other plts about RNAV ARR/DEP procedures it has become clr to me that there is a lot of confusion in general as to what is expected of flt crews. It seems the more I talk to people who have been airline plts a lot longer than me, I become even more confused with the subject. I keep getting 20 different answers from other plts and ctlrs and plts who have talked to ctlrs. I feel FAA should really provide some guidance and take away the ambiguity from procs"* (ACN 783805, 2008).

Another set of issues are *Clearance Amendments & NOTAMS* where modifications are made to the published procedure by the use of Notice To Airmen (NOTAM) or via ATC vectoring. A clearance amendment given mid-flight (in many cases) has caused pilot distraction or pilot confusion and increased procedural complexity. For example, one pilot reported that:

> *"the NOTAM changes many of the crossing restrs, and it is typical to get a dsnd via clrnc on this arr. I then read the changes to the capt and he entered them into the FMS. This distracted the capt from entering the new alt into the alt alerter, and me from verifying it… A few minutes I looked up at the mfd and realized we were….and still at FL220. I informed capt, he said he was unaware of receiving the crossing restr. We queried ATC, and were vectored of the arr and given a descent"* (ACN 803827 2008).

Approach Procedure Issues

Of the 285 reports in our data set, only 14 pertained to approaches. Twelve of these 14 indicated vertical deviations (85%). Seven of the 14 had a deviation in altitude at the final approach fix. Twelve of the 14 reports were from Part 91 operators. There were no particular identifiable trends among these 14 reports. The reason that so few approaches were identified in this data set may be because RNP approaches are typically specially authorized for particular aircraft and require aircrew training. These are relatively new procedures that receive limited usage by just a few airline operators.

SUMMARY AND CONCLUSIONS

New RNAV and RNP procedures are being developed and integrated into operations at a rapid pace. These new procedures create both opportunity and challenges. The introduction of these complex procedures has resulted in the emergence of several human factor issues.

Two key issues documented in the ASRS database are: (a) for departure procedures, deviations in the lateral domain such as dropped transition waypoints in the FMS and ATC off-path vectoring, (b) for arrival procedures, deviations in the vertical domain where altitude restrictions were not met due to confusion with "descend via" clearances given by ATC and amendments creating modifications to the already complex procedures. Data on approach procedures was too limited to make any strong conclusions.

Although the issues found in this analysis are not all specifically related to RNAV, they are exacerbated by the increasing implementation of RNAV procedures. Going forward, more complex procedures will be developed and resolutions for these issues should be identified for future implementations. The analysis revealed that the reported problems were a combination of pilot, ATC, aircraft automation, and procedure design. Thus, an integrated solution will be required.

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