Area Navigation and Required Navigation Performance Procedures and Depictions

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Area navigation (RNAV) and required navigation performance (RNP) procedures are fundamental to the implementation of a performance based navigation (PBN) system, which is a key enabling technology for the Next Generation Air Transportation System (NextGen). As new RNAV and RNP procedures are developed, they are published as charts for use by appropriately qualified pilots. These charts and procedures describe paths that must be flown precisely for improved use of airspace and safety. In this document, we consider how charts for both conventional and PBN procedures are designed from a human factors perspective. First, we document current charting challenges and mitigation strategies. Next, we describe a review of procedures that was done to discover which features were related to difficulty of use or visual complexity. The more difficult instrument approach charts depict procedures with more flight paths, path segments, and radius-to-fix legs. Standard instrument departure procedures that are more difficult show more flight paths. Standard terminal arrival route procedures that are more difficult have more total altitude constraints and path segments. Finally, we describe the process for designing and implementing new instrument procedures, which involves significant coordination both inside and outside the government.</td></tr>
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Preface

This document was prepared by the Aviation Human Factors Division of the John A. Volpe National Transportation Systems Center (Volpe Center) with assistance from the Massachusetts Institute of Technology (MIT) Department of Aeronautics and Astronautics. The Volpe Center was funded by the Federal Aviation Administration (FAA) NextGen Human Factors Division (ANG-C1). MIT was funded by Volpe Center through Contract No. DTR57-07-D-30006. Ms. Butchibabu conducted the chart review presented here as part of her work towards a Master's degree. Her adviser was Prof. R. John Hansman in the Department of Aeronautics and Astronautics.

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The views expressed herein are those of the authors and do not necessarily reflect the views of the Volpe National Transportation Systems Center, the Research and Innovative Technology Administration, or the United States Department of Transportation.

Feedback on this document may be sent to Divya Chandra (Divya.Chandra@dot.gov) or Rebecca Grayhem (Rebecca.Grayhem@dot.gov). Further information on this research effort is available at http://www.volpe.dot.gov/coi/hfrsa/ahf/ip/index.html.

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC		METRIC TO ENGLISH	
LENGTH (APPROXIMATE)		**LENGTH** (APPROXIMATE)	
1 inch (in)	= 2.5 centimeters (cm)	1 millimeter (mm)	= 0.04 inch (in)
1 foot (ft)	= 30 centimeters (cm)	1 centimeter (cm)	= 0.4 inch (in)
1 yard (yd)	= 0.9 meter (m)	1 meter (m)	= 3.3 feet (ft)
1 mile (mi)	= 1.6 kilometers (km)	1 meter (m)	= 1.1 yards (yd)
		1 kilometer (km)	= 0.6 mile (mi)
AREA (APPROXIMATE)		**AREA** (APPROXIMATE)	
1 square inch (sq in, in^2)	= 6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	= 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	= 0.09 square meter (m^2)	1 square meter (m^2)	= 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	= 0.8 square meter (m^2)	1 square kilometer (km^2)	= 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	= 2.6 square kilometers (km^2)	10,000 square meters (m^2)	= 1 hectare (ha] = 2.5 acres
1 acre = 0.4 hectare (he)	= 4,000 square meters (m^2)		
MASS - WEIGHT (APPROXIMATE)		**MASS - WEIGHT** (APPROXIMATE)	
1 ounce (oz)	= 28 grams (gm)	1 gram (gm)	= 0.036 ounce (oz)
1 pound (lb)	= 0.45 kilogram (kg)	1 kilogram (kg)	= 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	= 0.9 tonne (t)	1 tonne (t)	= 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)		**VOLUME** (APPROXIMATE)	
1 teaspoon (tsp)	= 5 milliliters (ml)	1 milliliter (ml)	= 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	= 15 milliliters (ml)	1 liter (l)	= 2.1 pints (pt)
1 fluid ounce (fl oz)	= 30 milliliters (ml)	1 liter (l)	= 1.06 quarts (qt)
1 cup (c)	= 0.24 liter (l)	1 liter (l)	= 0.26 gallon (gal)
1 pint (pt)	= 0.47 liter (l)		
1 quart (qt)	= 0.96 liter (l)		
1 gallon (gal)	= 3.8 liters (l)		
1 cubic foot (cu ft, ft^3)	= 0.03 cubic meter (m^3)	1 cubic meter (m^3)	= 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	= 0.76 cubic meter (m^3)	1 cubic meter (m^3)	= 1.3 cubic yards (cu yd, yd^3)
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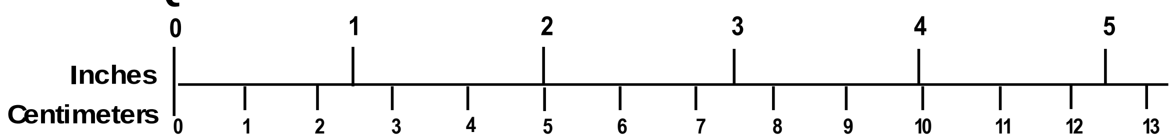

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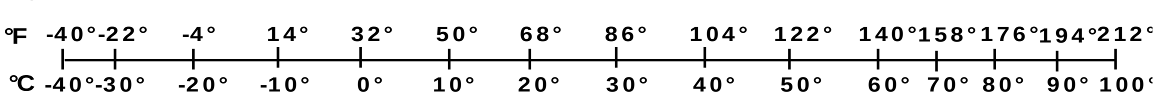

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Executive Summary

The Volpe Center Aviation Human Factors Division is sponsored by the Federal Aviation Administration (FAA) to examine the design, depiction, usability, and flyability of instrument procedures in order to reduce their susceptibility to errors by appropriately qualified pilots. Our main focus is on depictions of area navigation (RNAV) and required navigation performance (RNP) procedures, which are being developed in the transition to Performance Based Navigation (PBN) operations. The integration of RNAV and RNP with conventional procedures is also within the scope of this research because hybrid procedures are being developed. PBN operations are a key component of the evolution of the National Airspace System (NAS) towards the Next Generation Air Transportation System (NextGen).

RNAV and RNP procedures need to be designed such that they can be clearly depicted and used by pilots. The Performance Based Navigation Aviation Rulemaking Committee (PARC) RNP Chart Saturation Action Team was tasked in 2009 and 2010 to review concerns and prepare recommendations related to RNAV (RNP) approach procedures that are difficult to depict. Similar concerns were discussed in other groups, such as the Aeronautical Charting Forum.

This report is a primer on charting issues for human factors researchers. Our approach was to learn as much as we could from subject matter experts, websites, and available industry literature, such as presentations and meeting notes. We summarized and documented this information in a way that highlights open issues that are researchable. We also conducted an analysis of charts that is summarized here and presented in detail in a separate report (Butchibabu and Hansman, 2012).

We focus on the charting of RNAV and RNP procedures that are graphically depicted in a pre-composed, static format originally designed for distribution in paper form. These charts are now available on electronic devices in Portable Document Format (PDF), which are still static and pre-composed images. Although dynamic, data-driven electronic charts are envisioned for the future, pre-composed charts (both electronic and paper versions) are expected to be in use for the foreseeable future. Because we address the content of charts and not just their format, our work has implications for data-driven electronic charts as well. Arrival, departure, and approach procedures are considered equally throughout this report. In addition, our observations may also be applicable to charts for conventional procedures, not just RNAV and RNP procedures.

The report is divided into three sections. First, we describe current charting challenges and potential mitigations for these challenges. We examined charts from different manufacturers for different airports, both within and outside the United States (US), in order to understand what techniques have been used for handling challenging cartographic situations. Some strategies include use of summary tables and not-to-scale sections of the graphical route depiction.

After reviewing charting challenges and mitigation strategies, we were interested to know whether any objectively identifiable parameters of a procedure were correlated with difficulty of use. For this analysis, we compared two sets of RNAV and RNAV (RNP) charts in terms of different objective variables. One set of procedures was selected from those with operational issues noted in a review of Aviation Safety Reporting System (ASRS) reports (Butchibabu, Midkiff, Kendra, Hansman, and Chandra, 2010) or were highlighted by subject matter experts as being unusually complex; these were placed in the "Problematic" set. The second set of procedures, labeled "Baseline," consisted of RNAV and RNAV (RNP) procedures from a set of 35 commercial airports in the US with significant activity (formerly known as the Operational Evolution Partnership airports) that did not appear in the Problematic set.

Data were gathered from 63 RNAV (RNP) approach procedures, 52 RNAV Standard Instrument Departures (SIDs), and 54 RNAV Standard Terminal Arrival Routes (STARs). For approaches, we recorded attributes such as the number of flight paths shown, the total number of segments per path, and the number of curved segments. For SID and STAR procedures we recorded a slightly different set of variables (e.g., number of flight paths, number and types of altitude constraints, the types of altitudes depicted, distances along the different route segments, and overall distance for each path). For approaches, the main differences between the Problematic and Baseline sets were that the Problematic set had (a) more flight paths (b) more path segments, and (c) more curved (radius-to-fix) segments. For SID procedures, the Problematic set had more flight paths. For STAR procedures, the Problematic set had more path segments and more altitude constraints.

Finally, we provide background information on how procedures are designed and implemented, who is involved in the process, and the documents that specify the process. Procedure development involves the coordination of many individuals with different areas of expertise, across different branches of the FAA and between the FAA and operators. This process is currently changing, as lean management processes are put into place. One observation about this process is that instrument approach procedures are regulatory in nature and therefore have little flexibility in their design and use. However arrivals and departures are not regulatory and can be used in a more flexible manner by Air Traffic Control.

We conclude with suggested topics for future human factors research on aeronautical charting.

Acronyms and Abbreviations

AC	Advisory Circular
AFS	FAA Flight Standards Service
ARINC	Aeronautical Radio Incorporated
AJV-3	FAA National Aeronautical Navigation Products
ALPA	Air Line Pilots Association
AOI	Airport Operational Information
AR	Authorization Required
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATL	Atlanta International Airport, Georgia
AVN	Aviation Systems National Field Office
BOI	Boise Air Terminal, Idaho
BWI	Baltimore/Washington International Airport, Maryland
BZN	Bozeman Airport, Montana
CAASD	Center for Advanced Aviation Systems Development
CDA	Continuous Descent Approach
CDU	Control and display unit
CFIT	Controlled Flight into Terrain
CFR	Code of Federal Regulations
CLT	Charlotte/Douglas International Airport, North Carolina
CVG	Cincinnati/Covington International Airport, Ohio
DC	District of Columbia
DCA	Reagan Washington National Airport, District of Columbia
DFW	Dallas/Fort Worth International Airport, Texas
DME	Distance Measuring Equipment
EDDF	Frankfurt Airport, Germany
EFB	Electronic Flight Bag
EGKK	Gatwick Airport, United Kingdom
EWR	Newark International Airport, New Jersey
FAA	Federal Aviation Administration
FAF	Final Approach Fix
FLL	Fort Lauderdale/Hollywood International Airport, Florida
FMC	Flight Management Computer

FMS	Flight Management System
FPT	Flight Procedures Team
GPS	Global Positioning Satellite
HDN	Hayden Airport, Colorado
HOU	William P. Hobby Houston Airport, Texas
IACC	Interagency Air Cartographic Committee
IAD	Dulles Airport, Virginia
IAF	Initial Approach Fix
IAH	George Bush Houston Intercontinental Airport, Texas
IAP	Instrument Approach Procedure
IAPA	Instrument Approach Procedure Automation
ICAO	International Civil Aviation Organization
IPDS	Instrument Procedure Development System
IF	Intermediate Fix
IFP	Instrument Flight Procedure
IFR	Instrument Flight Rules
ILS	Instrument Landing System
JFK	John F. Kennedy New York International Airport, New York
L	Left
LAS	Las Vegas International Airport, Nevada
LAX	Los Angeles International Airport, California
LGA	La Guardia New York Airport, New York
LGB	Long Beach Airport, California
LOC	Localizer
LOWI	Innsbruck Airport, Austria
LSZH	Zurich Airport, Switzerland
LWS	Lewiston-Nez Perce County Airport, Idaho
MAP	Missed Approach Point
MCO	Orlando International Airport, Florida
MEA	Minimum En Route Altitude
MIA	Miami International Airport, Florida
MIT	Massachusetts Institute of Technology
MOCA	Minimum Obstacle Clearance Altitude
MSP	Minneapolis-St. Paul International Airport, Minnesota

NACO	National Aeronautical Charting Office (now FAA AeroNav Products)
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	Navigation display
NextGen	Next Generation Air Transportation System
NM	Nautical mile
ODP	Obstacle Departure Procedure
OEP	Operational Evolution Partnership
PFAF	Precision Final Approach Fix
PANS-OPS	Procedures for Air Navigation Products-Aircraft Operations (ICAO)
PARC	Performance Based Navigation Aviation Rulemaking Committee
PBI	Palm Beach International Airport, Florida
PBN	Performance Based Navigation
PDF	Portable Document Format
PDK	DeKalb-Peachtree Airport, near Atlanta, Georgia
PDX	Portland International Airport, Oregon
PHL	Philadelphia International Airport, Pennsylvania
PHX	Phoenix Sky Harbor International Airport, Arizona
PSP	Palm Springs International Airport, California
R	Right
RAPT	Regional Airspace and Procedures Team
RDU	Raleigh-Durham International Airport
RF	Radius-to-fix
RIL	Rifle Regional Airport, Colorado
RNAV	Area Navigation
RNP	Required Navigation Performance
RWY	Runway
SAAAR	Special Aircraft Aircrew Authorization Required
SAN	San Diego International Airport, California
SEA	Seattle-Tacoma International Airport, Washington
SEQU	Mariscal Sucre International Airport, Ecuador
SDL	Scottsdale Airport, Arizona
SLC	Salt Lake City International Airport, Utah
SFO	San Francisco International Airport, California

SID	Standard Instrument Departure
SIDPT	Standard Instrument Departure Procedure Text
SME	Subject Matter Expert
SNA	Santa Ana/Orange County Airport, California
STAR	Standard Terminal Arrival
TEB	Teterboro Airport, New Jersey
TERPS	Terminal Instrument Procedures
TPA	Tampa International Airport, Florida
US	United States
VFR	Visual Flight Rules
VHF	Very High Frequency
VNAV	Vertical Navigation
VNKT	Tribhuvan International Airport, Kathmandu, Nepal
VOR	VHF Omnidirectional Range
ZULS	Gonggar Airport, Lhasa, China

1 Introduction

The Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) are transitioning to Performance Based Navigation (PBN) operations. PBN operations are a key component of the evolution of the National Airspace System (NAS) towards the Next Generation Air Transportation System (NextGen).

A fundamental component of PBN is the use of area navigation (RNAV) procedures. RNAV procedures allow aircraft to fly directly between points in space without relying on ground-based navigation aids (e.g., by using satellite-based navigation). Required navigation performance (RNP) is a refinement of RNAV that includes on-board monitoring and alerting to ensure that the actual performance of the navigation system keeps the aircraft position within established criteria. Because RNP is essentially a type of RNAV procedure, we refer to RNAV routes with RNP segments as RNAV (RNP) procedures in this document. The parenthetical RNP alerts the flight crew to the RNP segments in the procedure, but because it is parenthetical, Air Traffic Control (ATC) does not mention RNP in their communications with the crew about the procedure.

RNAV and RNP procedures offer safety enhancements along with new levels of flexibility to negotiate terrain, airspace, and environmental considerations. RNAV and RNP allow more precise path design, which is particularly useful for developing approach procedures to runways. For example, RNP approaches often include radius-to-fix (RF) path segments (i.e., precisely curved legs) to avoid obstacles.

Figure 1, from the FAA website, illustrates the design efficiencies that RNAV and RNP afford relative to conventional routes. RNAV alone allows for additional airspace efficiency, as seen by the rectangular airspace boundaries in place of the trapezoidal boundaries required for conventional navigation aids. Paths can be more precise with RNAV, as illustrated by the reduced width of the rectangles. With RF legs, curved paths can be created to avoid terrain or other areas such as special use airspace or noise abatement regions. RNP paths can be even more precise than RNAV paths (as illustrated by the even narrower rectangles) because of the aircraft monitoring and alerting capabilities.

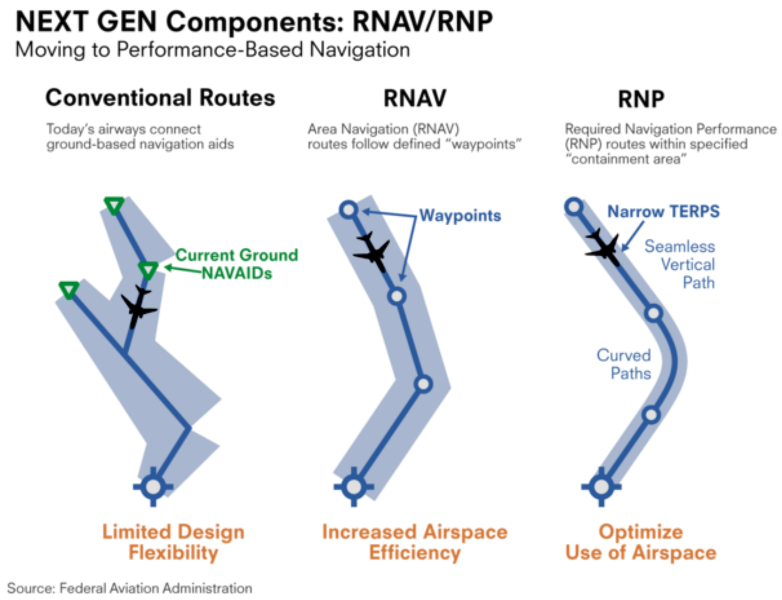

Figure 1. RNAV and RNP routes compared with conventional routes.

More RNAV procedures, with and without RNP segments, are being developed each year in order to support PBN (FAA, 2012a; MITRE CAASD 2011). The FAA is committed to developing RNAV and RNP procedures, particularly those with large operational benefits, as part of its response to recommendations made by RTCA (FAA, 2010a) and in response to legislative requirements. Further information on RNAV and RNP can be found in a variety of FAA handbooks and reports (FAA 2006, 2007a, 2008, 2012a, 2012b).

The aircraft must be properly equipped and the crew must be trained appropriately to fly RNAV (RNP) approaches that are “Authorization Required” (AR).[1] RNP AR procedures ensure that the crew and aircraft meet specific requirements for both position determination and track conformance. ATC is not required to monitor path conformance for these approach procedures.

Training requirements for RNAV procedures are contained in Advisory Circular (AC) 90-100A (FAA, 2007b), for RNP operations and barometric vertical navigation in AC 90-105 (FAA, 2009), and for RNAV (RNP) AR procedures in AC 90-101A (FAA, 2011a). Pilots must be familiar with both text and graphical depictions of RNAV and RNAV (RNP) procedures. From these, they must be able to understand the flight path, determine equipage requirements for the individual procedure, and be able to use and understand RNAV and RNP terminology, as well as specific air traffic phraseology. Pilots must also be able to understand and use RNAV and RNP information that is system-specific, such as flight deck automation and alerting interfaces. Pilots must be able to operate RNAV equipment appropriately (e.g., initialize system position and use the Flight Management System, to monitor the flight path and adhere to speed and/or altitude constraints associated with the procedure). Finally, pilots must be able to execute contingency procedures in case of RNAV and RNP failures.

There are human factors concerns with RNAV and RNAV (RNP) instrument procedures because they can result in paths that are complex to fly manually and typically require the assistance of a Flight Management System (FMS) to negotiate precise speed, altitude, and lateral path constraints. To date, all approaches with RNP segments require the use of an FMS. Consider, for example, the plan view of the approach procedures to Boise, Idaho as shown in Figure 2 below. The localizer back course approach is a less common (and somewhat more difficult) approach. In contrast, the RNAV (RNP) Z approach is visually complex, but when flown with automation, it may allow increased safe access to the runway.

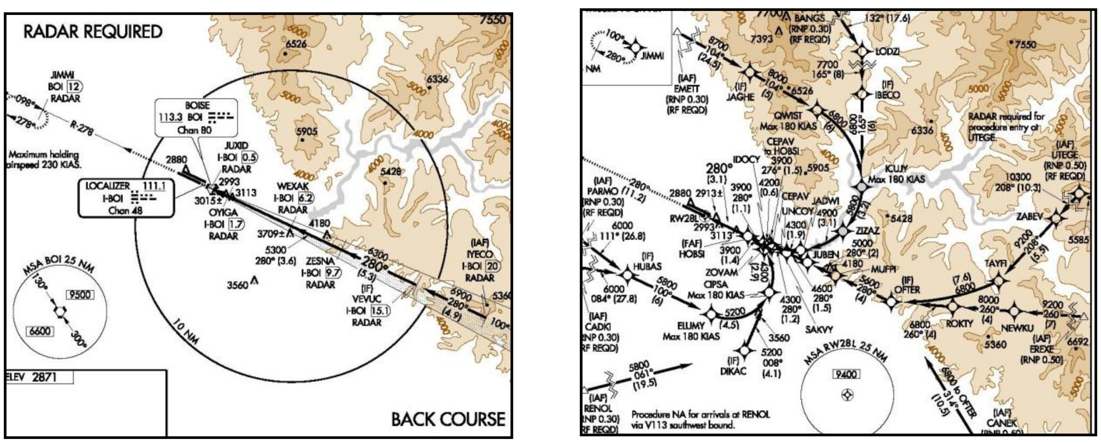

Figure 2. Localizer Backcourse Runway 28L at Boise, Idaho (left) and RNAV (RNP) Z Runway 28L (right).

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[1]AR is the term used now by both the United States (US) and ICAO. An older term “Special Aircraft Aircrew Authorization Required” (SAAAR) was previously used in the US only.

In this document we refer to both procedures and charts. We adopted a similar definition as in AC 211-2 (FAA, 1967) such that a *chart* refers to a document specifically created to meet the requirement of air navigation which provides a graphic representation of a specific published procedure used to aid pilots in the navigation of an aircraft. A *procedure* refers to the information and requirements set by the FAA. In other words, the chart is the *depiction* of the *procedure*.

A list of human factors issues related to RNAV and RNAV (RNP) procedures was first collected and summarized by Barhydt and Adams in a comprehensive research report (2006a). Charting and depiction of these procedures is one of the many topics covered in that report.

Separately, Barhydt and Adams (2006b) conducted an exploratory study of events reported in the Aviation Safety Reporting System (ASRS) database. They identified 124 reports filed between 2000 and mid-2005 related to problems experienced by flight crews with RNAV departure and arrival procedures at seven specific airports. This analysis was updated by Butchibabu, Midkiff, Kendra, Hansman, and Chandra (2010). The 2010 analysis is more detailed and classifies different types of human factors issues presented in 285 relevant reports that were filed between January 2004 and April 2009. Butchibabu et al. found 59 reports in their set that mention charting and procedure issues, though it was not possible to tell whether the origin of the issue was in the *depiction* of the procedure (i.e., the chart's graphic format, layout, etc.) or in the *design* of the procedure (i.e., the defined paths). Butchibabu et al. (2010) and Barhydt & Adams (2006b) both also found that issues with RNAV procedures have a complex combination of factors related to air traffic operations, pilot interpretation of procedures, and procedure design challenges related to aircraft automation and charting.

We consider charts for Standard Terminal Arrival Routes (STARs), Standard Instrument Departures (SIDs), and Instrument Approach Procedures (IAPs) (also referred to as "approach" procedures) in this research. Although pilots may consider the approach procedures to be part of the arrival procedure, we distinguish between the two because different charts are used.

2 Charting Challenges for RNAV and RNP Procedures

Static, pre-composed charts are developed for all procedures, including new RNAV and RNAV (RNP) procedures. The charts provide the pilot with all information necessary to fly the procedure, under all allowable conditions. Charts can be used to verify that the aircraft is following the correct path laterally, vertically, and in terms of speed. The paths may be complex, with multiple legs and transitions. The published charts provide the pilot with all information relevant to the procedure. They show the path that the aircraft is intended to fly along with any other paths that might otherwise be flown, if so directed by ATC. In addition, the chart shows the minimum weather conditions under which the procedure can be completed, essential equipment requirements, restrictions, and other constraints for flying that procedure.

In the past, the chart was the primary source of information to fly the procedure. However, aeronautical charts are not certified by the FAA or even legally mandated to be carried on the flight by many Part 91 (private) operators. An FAA Advisory Circular from 1967 is the current document for "recommended standards for IFR aeronautical charts"; these standards are recommended, not required. The following sections from Title 14 Code of Federal Regulations (CFR) mention or imply use of aeronautical charts, often in a general way.

a) Part 91.103, Preflight Actions, applies to all Part 91 operators. It states that each pilot in command "shall, before beginning a flight, become familiar with all available information concerning that flight."
b) Part 91.503, Flying Equipment and Operating Equipment, applies to Part 91 operators of large and turbine powered airplanes, and fractional ownership program aircraft. It requires the pilot in command to ensure that aeronautical charts and data, in current and appropriate form, are accessible for each flight at the pilot station of the airplane. Part 91.503 also requires the pilot to have "pertinent aeronautical charts" and, for IFR, Visual Flight Rules (VFR) over-the-top, or

night operations to have "each pertinent navigational en route, terminal area, and approach and letdown chart."

c) Part 121.549, Flying Equipment, applies to scheduled carriers and states that the pilot in command "shall ensure that appropriate aeronautical charts containing adequate information concerning navigation aids and instrument approach procedures are aboard the aircraft for each flight."

d) Parts 125.215 and 135.83, Operating Information Required, apply to charter and air taxi services. These requirements specify only that the operator must have "pertinent aeronautical charts."

Nowadays, electronic flight deck systems and displays (e.g., the FMS, navigation display, or other moving map display) are another source of information about the procedure. These systems obtain data from the onboard navigation database, which contains procedure information in a specially encoded form. The flight path being flown (or expected to be flown) is typically depicted graphically on the Navigation Display (ND) and a text description of the route can be found in the FMS Multifunction Control and Display Unit (MCDU). Although the navigation database can provide a basic display of the applicable waypoints, the lateral and vertical paths, and certain restrictions, other necessary procedure information may only be shown on the published (static) chart. In other words, the published chart provides all information determined to be relevant by the procedure designer, whereas the navigation display mainly provides information about specific flight paths.

The pilot cross-checks the two separate sources of data, the chart and the flight deck systems. However, the chart contains a much more complete set of data for the operation. For example, the paper chart also contains information that may be used only in unusual circumstances or in-flight contingencies such as equipment failures, lost communications, or a missed approach. Under normal circumstances, however, the pilot may depend upon the automation to fly the path defined in the database, as long as he or she verifies that the correct procedure and constraints are loaded and active in the FMS. Anecdotal evidence suggests that air carrier pilots, who have used flight management systems for many years now, are comfortable relying upon the flight deck systems to fly to the correct waypoints, but they still confirm that the correct waypoints are loaded in the FMS. There is currently no data on how much pilots rely upon the paper chart versus the graphical representation of the associated procedure provided by onboard navigation displays.

Charts for RNAV and RNAV (RNP) procedures can be visually distinct from charts for conventional procedures such as an ILS procedure. ILS procedures are essentially a straight path to the runway as shown in Figure 3. The large arrow-shape of the localizer symbol on the chart directs attention to the runway. Figure 4 shows an RNAV procedure into the same airport as shown in Figure 3. Rather than following a funnel-shaped signal for the ILS, where the signal width increases with the distance from the runway, the RNAV procedure provides a constant width path (that is, a tube instead of a funnel). Figure 5 shows an RNAV (RNP) procedure at the same airport as in Figure 3, this time with multiple paths and curved RNP segments on the procedure. The curved segments are called radius-to-fix (RF) legs. The combination of RF legs, multiple initial approach fixes (IAFs), and even multiple intermediate fixes (IFs) can create a visual depiction that varies greatly from one RNAV (RNP) procedure to the next, unlike ILS procedures which are relatively standardized in their overall appearance. Sometimes, just locating the runway on the RNAV (RNP) approach procedure can take effort.

In most cases, the RNAV (RNP) approach procedure concludes with a straight-in segment from the final approach fix (FAF)[2] to the runway, but there are cases where there are several segments with heading changes and RF legs *between* the FAF and runway threshold. The Washington National Airport RNAV

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[2] The final approach segment technically begins at the precision final approach fix (PFAF) per FAA Order 8260.52. However, this point is commonly referred to as the final approach fix (FAF), so we use this term as well.

and RNAV (RNP) approach procedure to Runway 19 is an example of this situation (see Figure 6). The additional waypoints after the FAF do not necessarily increase the complexity of flying the procedure with flight deck automation, but they do increase the visual complexity of the depiction.

Overall, it appears that the performance-related characteristics of RNAV (RNP) approach procedures result in more visual elements that must be depicted than most conventional procedures based on radio navigation aids. This can result in both increased operational complexity and increased difficulty in constructing, depicting, and actually using the graphic depiction of a given procedure, not just for approaches, but also for STAR and SID procedures. Samples of two visually complex SID procedures at Salt Lake City, Utah, are provided in Figure 7 and Figure 8. These examples show that even the orientation of the procedure on the page can be rotated to accommodate the shape of the procedure; Leetz is in landscape format while Wevic is in portrait format.

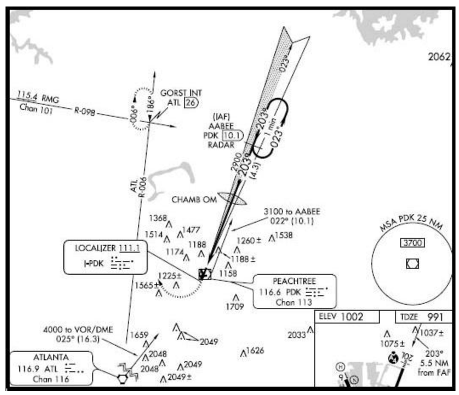

Figure 3. ILS procedure into DeKalb-Peachtree Airport (KPDK).

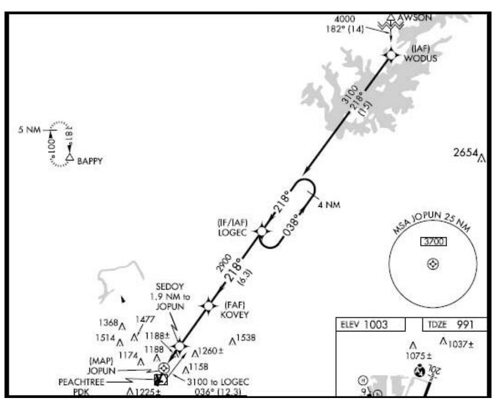

Figure 4. RNAV approach procedure into DeKalb-Peachtree Airport (KPDK).

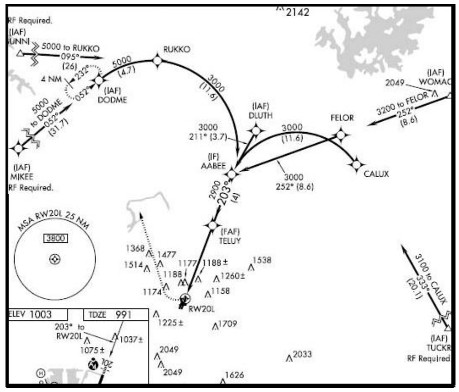

Figure 5. RNAV (RNP) approach procedure into DeKalb-Peachtree Airport (KPDK).

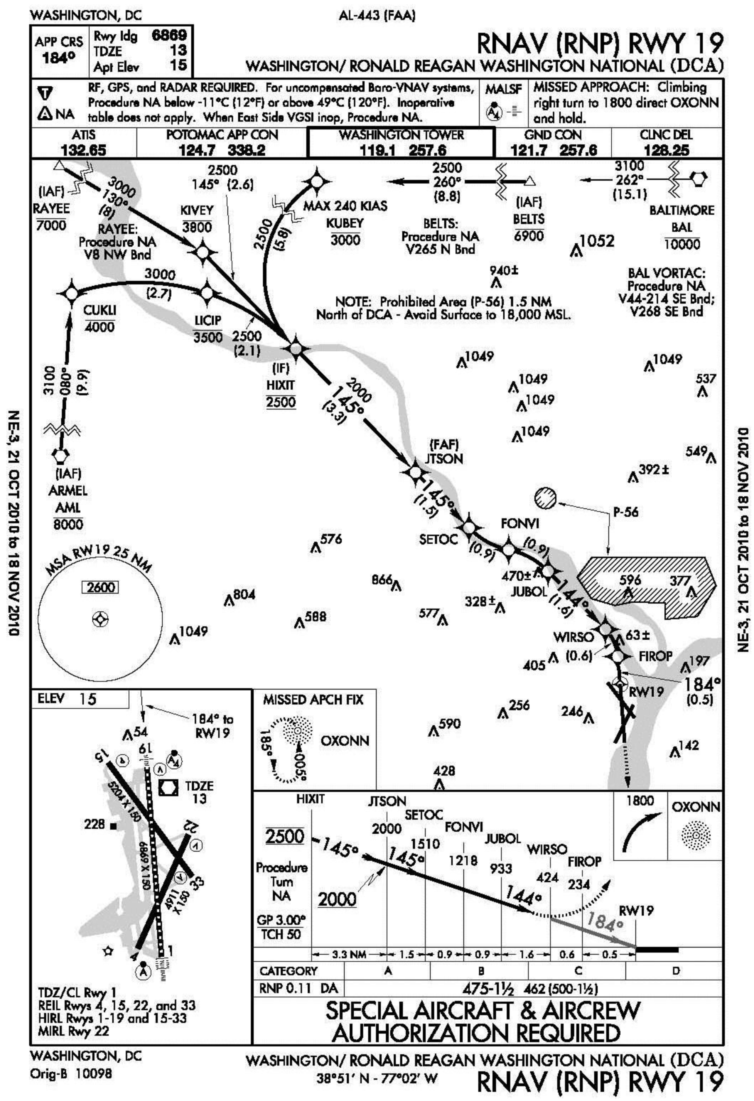

Figure 6. Washington, DC approach procedure with multiple turns after the final approach fix (JTSON).

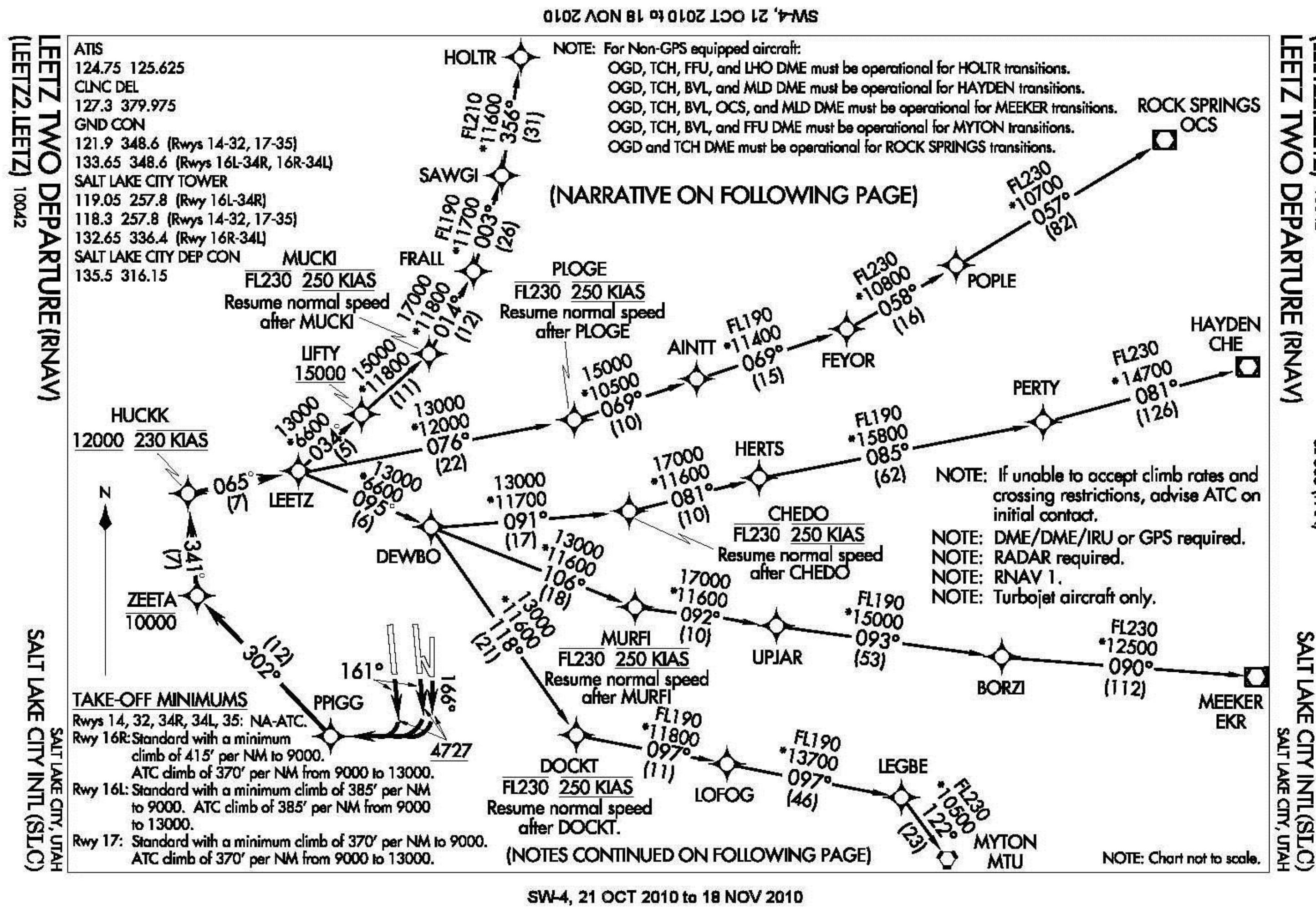

Figure 7 Salt Lake City Leetz Two RNAV Departure.

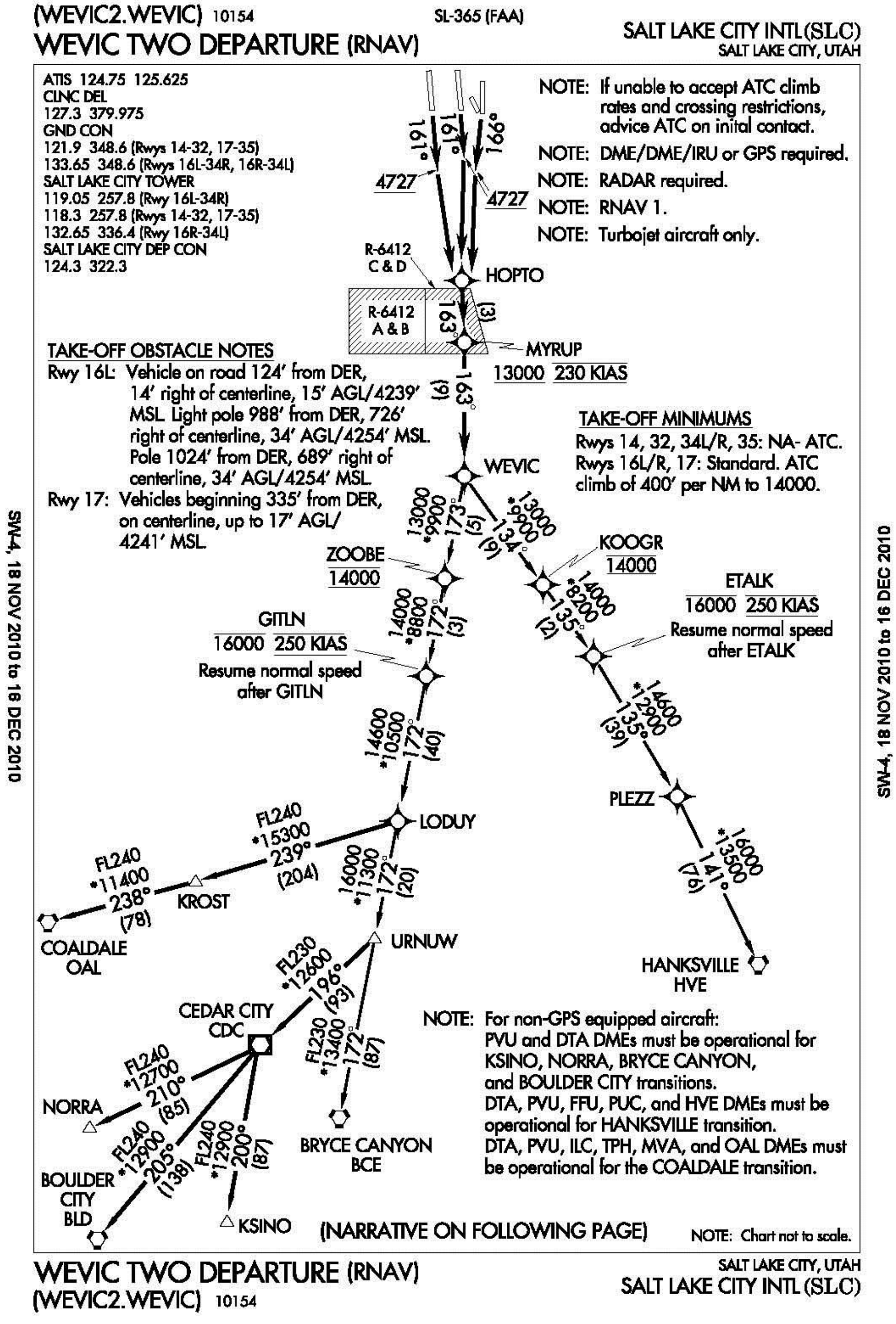

Figure 8 Salt Lake City Wevic Two RNAV Departure.

Recently developed RNAV (RNP) approaches into Boise, Idaho provide more cases of unusual procedures and corresponding charts (see Figure 9 for an example). Figure 10 shows corresponding photos of the CDU and ND for the Boise approach to Runway 28R. This approach procedure, and others like it at Boise and other airports, was the subject of a special action team organized under the Performance Based Navigation Aviation Rulemaking Committee (PARC) in 2009-10.

Besides the visual complexity of the Boise Runway 28R plan view, there is another unusual feature of this approach in the profile view. Normally, there is only one IF in the approach procedure and the full altitude profile beginning from that IF is shown in the profile view (e.g., San Francisco or Atlanta). In the Boise procedure there are numerous paths available to the runway from multiple intermediate fixes. It is not possible to show all of the possible vertical flight path options in the one profile view as they would normally be depicted, from the intermediate fix to the runway. Instead, a special FAA waiver was granted to only show the vertical path in the profile view starting from the FAF (Aeronautical Charting Forum, 2009).

Concern about the usability of the Boise RNAV (RNP) approach procedures is mitigated because they are AR procedures that require special crew training and authorization and an FMS. However, questions remain about the complexity, readability, and overall usability of these procedures. For example, what level of visual clutter is acceptable on the plan view? Does the lack of complete information in the vertical profile view affect pilot comprehension and performance of the procedure, even with special training? In addition, questions remain about whether such a waiver could or would ever be granted for other RNAV (RNP) procedures, or for other similarly complex non-AR procedures.

To date, charts are typically used in a static, pre-composed format. These formats are limited in size. They also have constraints on the information that must be depicted (e.g., legal requirements to show all information provided on official government procedure sources that may not be used frequently during normal operations). The combination of complex procedure design and the limited flexibility of static, pre-composed charts creates difficulties for both chart manufacturers, who are responsible for providing all the appropriate procedure information and optimizing the readability of the chart, and for pilots who ultimately use the charts in flight. Although static, pre-composed charts may be more constrained than the dynamic, data-driven electronic navigation displays in terms of customizing information relevant to a specific flight path, they do have some positive attributes. In particular, paper typically has a high resolution, which allows for flexibility such as the use of small fonts, subtle linear patterns, and shading. Paper is also easy to read in many different lighting conditions.

Customizable electronic charts are also in development. For example, Lufthansa Systems/Lido provides customizable electronic charts as part of their Lido/eRouteManual. Jeppesen already provides electronic data-driven en route applications for use on Electronic Flight Bags (EFBs) and other mobile platforms. These emerging systems are rapidly being accepted and approved for in-flight operational use. While electronic data-driven charts may solve some of the related issues, they may also bring a new set of issues to the forefront. For example, electronic charts may require panning and zooming to be able to see and read all of the information. Chart selection is also potentially more problematic with electronic displays of charts because of limits to chart naming conventions, such as those imposed by limitations in the number of characters available to be displayed in current CDUs.

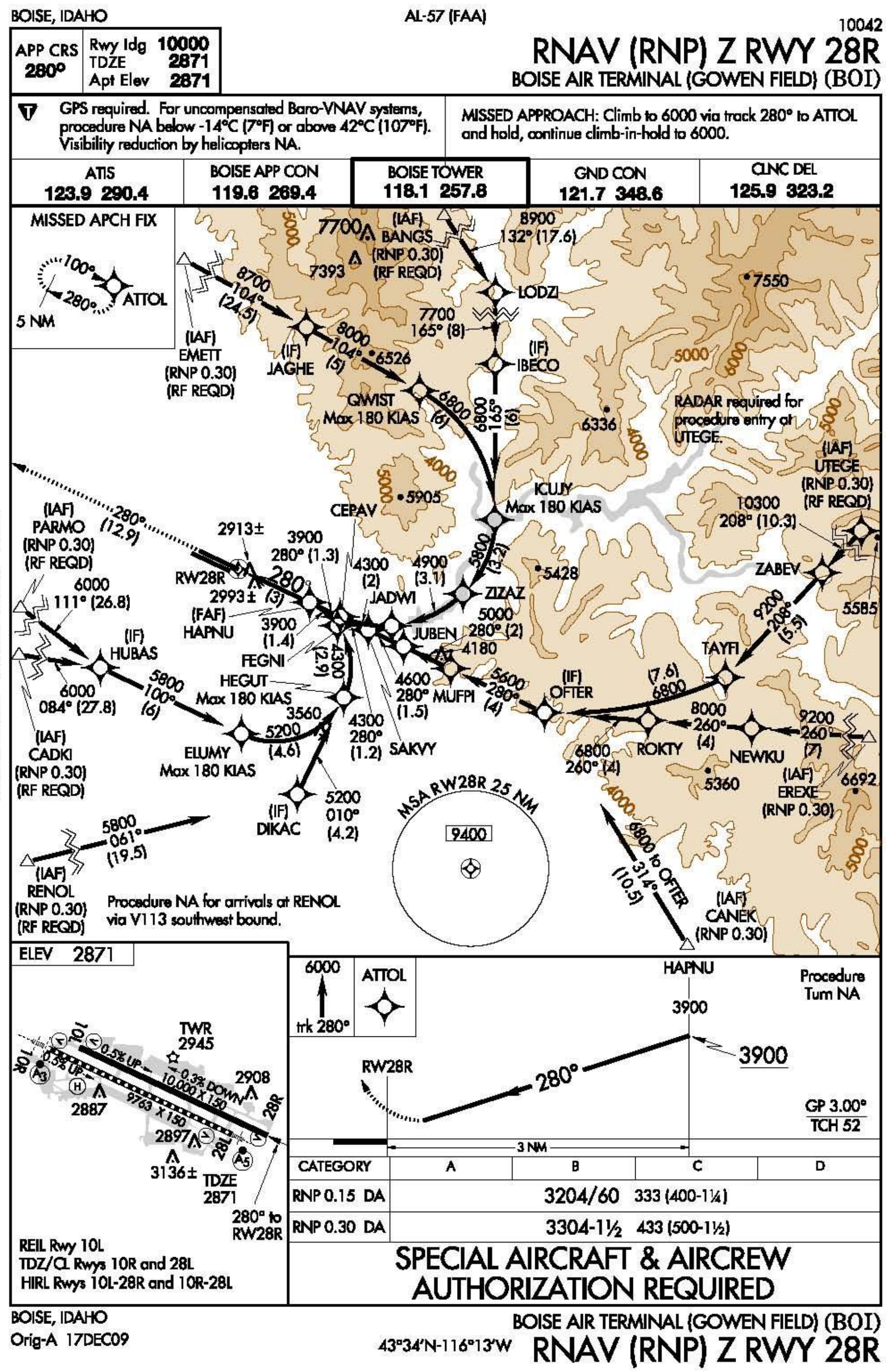

Figure 9. RNAV (RNP) Approach into Boise Runway 28 Right.

Figure 10. Boise runway 28 Right, final segment of the Emett transition on the CDU (left) and ND (right).

Photos courtesy of Pedro Rivas.

3 Charting Options

The purpose of this section is to identify techniques that have been used to date by chart manufacturers to handle the depiction of visually complex procedures. We focus on high-level issues and distinctions, but do not document every difference between manufacturers. Procedures can change as often as every few months. Charting conventions can also change over time. Therefore, the issues we discuss may be handled differently in the future.

In this section, we assume that the procedure design is a given; it cannot be changed once the procedure has been defined. There are only three options for handling visually complex procedures at this point, listed below. These options are discussed in Sections 3.1, 3.2, and 3.3.

1) Use unconventional graphical techniques to optimize the presentation of all appropriate information within limited available space (e.g., including use of a larger sized chart format)
2) Separate (i.e., split out) the information across more than one chart, and
3) Remove (i.e., omit) “less important” or “contingency” information from the chart based on the needs of the specific intended user (e.g., aircraft type or available equipment).

3.1 Graphical Design

Manufacturers use graphic design techniques to customize the look and feel of their products; these same techniques can also help to make the chart more usable. However, manufacturers are finding these tools are strained with the increased information needs for RNAV and RNAV (RNP) procedures. The techniques we describe in this section illustrate just a sample of the options; new ideas are always in development.

Procedures developed for international and domestic airports were reviewed as part of this effort. Some of the international examples are not RNAV procedures, but they do illustrate some innovative graphic design options, including a “routing strip,” separating information across pages, use of insets and varied scales, naming of paths within the depiction, and use of numbering to clarify what information is related.

Table 1 lists the international charts that we examined along with notes about their characteristics both in terms of the graphic design and the procedure design. The procedure design is described because that can impact the complexity of the visual design and overall workload of the procedure. The international charts were provided to the authors as a courtesy from Jeppesen in 2009 and 2010. FAA Aeronautical Navigation (AeroNav) Products produces charts for the US NAS only.

Table 1. International procedures reviewed.

Airport and Procedure	Graphic Design	Procedure Design
Frankfurt Main, Germany (EDDF) OSMAX 07, RWYS 07L/R RNAV Transition, 10-2B GED 07, RWYS 07L/R RNAV Transition 10-2C	– Both have routing strip that is a text description of the path in a table format. The strip includes a list of all waypoints and constraints. – Both have numbered insets for information about the Final Approach near the runway to reduce clutter. The insets are not boxed.	– OSMAX 07 has unusual descent profile (back and forth parallel to runway). – GED 07 has a minimum speed and many restrictions. – Both have waypoints every 4 miles regardless of whether there was an altitude or heading change.
London Gatwick, United Kingdom (EGKK) ILS DME RWY 08R Initial Approach, 21-2 and Final Approach 21-2A	– Information separated into initial and final approach. Both pages required. – Initial Approach contains all information until 9 miles to runway and Final Approach contains only information from that point to the runway. – Numbered text notes and a Not-to-scale inset box (outlined in dashes) on the Initial Approach page.	– Has a two anchor-point holding pattern.
Innsbruck, Austria (LOWI) LOC DME EAST 11-1	– Profile view with shaded terrain. – Plan view with shaded terrain. – Numbered text notes in the profile view. – Ground visibility and ceiling requirements on a separate page. – Minimums are in a small note.	– Steep glide slope (3.8 degrees).
Zurich, Switzerland (LSZH) WILLISAU2 SID, 10-3E	– Each path is referenced by name (e.g. 2D, 2C, 2Q, 2R). – Numbered text note for Minimum Safe Altitude box.	– Curved paths with no waypoints until the straight segment. – Visual conditions only for takeoff on runway 16.
Quito, Ecuador (SEQU) RNAV (RNP) RWY 17, 12-20 and RNAV (RNP) RWY 35 12-21	– Procedure divided into two sections with a discontinuity between sections. Top is drawn not-to-scale and bottom is to-scale. – Numbered text notes. – Inset box for missed approach fix. – Profile view notes left turn arc for RF leg.	– Terrain critical. – Speed limit on missed approach. – Turns inside the Final Approach Fix for Runway 17.
Kathmandu, Nepal (VNKT) VOR DME Circling via IGRIS, 13-2	– Inset box for missed approach fix. – Two missed approach points (both marked “M”) on the profile view, with a text note indicating that one is for nighttime operations. – Plan view with shaded terrain.	– Missed approach path start segment differs during day versus night.
Kathmandu, Nepal (VNKT) VOR DME Rwy 02, 13-1	– Plan view with shaded terrain.	– Terrain critical. – Procedure begins at IF. No IAF. – Minimum ceiling height required. – Circle to land not authorized at night.
Lhasa, China (ZULS) ILS DME Rwy 27R 11-1	– Plan view with shaded terrain. – Contains inset for not-to-scale segment, without terrain. – Feet to meter conversion table inside the plan view.	– Terrain critical. – Missed approach with no holding pattern and no further information.

3.1.1 Font Selection

Font sizes and styles such as underlining, italics, and bolding can be used to convey the importance of a specific piece of text. However, manufacturers are aware that overuse of different font cues can be counterproductive, making the information less usable overall. In addition, font styles on paper and pre-composed charts are static, so information that is emphasized through bolding, for example, may or may not be appropriately salient for all situations.

3.1.2 Color and Shading

Color and shading are often used to distinguish supplemental information from procedure information. For example, chart manufacturers use color and shading to indicate topographic features. Shading has also been used in the profile view of an approach chart to depict some altitude limits or constraints. For example, Segment Minimum Altitudes may be shown as shaded blocks. Colors may also be used to differentiate between types of information such as airspace boundaries, or to associate text labels with applicable elements. However, in the case of paper charts, color printing increases cost and not all manufacturers may be able to support this option. Also, the use of color and shading may pose other complications when chart images are displayed on electronic devices. For example, lighting and display resolution can affect the usability of color and shading on electronic platforms.

3.1.3 Scale

The plan view of an approach procedure chart is drawn to-scale by all chart manufacturers. Any aspects of the plan view that cannot be depicted to scale are indicated as such. For example, when there is a long transition route on the procedure, a portion of the route may be shortened and marked as such.

For a typical ILS procedure, the plan view shows the area approximately 20 to 30 miles around the landing airport. However, RNAV (RNP) procedures sometimes extend well beyond this range, so the scale of the view has to be reduced to cover a larger geographic area. If only one scale is used to accommodate the longest routes or to include the most distant fixes within the plan view, it may be difficult to clearly depict shorter or more complex flight paths near the airport.

In some cases, the plan view is broken into sections that use different scales. For example, in an approach chart for Quito, Ecuador (described in Table 1), the plan view is divided into two sections, with the top part drawn “not-to-scale” and the lower part drawn “to-scale.” In other cases, inset boxes may be used to depict regions that are out of range based on the scale of the main plan view.

Vertical profile views on charts are best depicted schematically (i.e., not to scale) due to the variety of distances they represent. The horizontal and vertical distances are distorted to fit into the available space while maintaining the sequential order and general spatial relationships between key reference points. This allows the manufacturer to highlight important aspects of the vertical flight path, such as minimum altitude limits or constraints, appropriately.

SID and STAR procedures may or may not be drawn to-scale, depending on the individual manufacturer’s conventions. FAA SID and STAR charts are not drawn to scale. Jeppesen SID and STAR charts are not usually drawn to scale, but might be in some cases. Navtech and Lufthansa Systems/Lido SIDs and STARs are drawn to scale. For the Lido charts, the congested areas nearest to the airport are always drawn to-scale. Any portions of a SID or STAR that are not-to-scale are clearly marked as such.

3.1.4 Graphical Versus Text Information

Arrival and departure procedures are typically described in a graphic representation and a text description of the procedure. On Jeppesen charts, both the graphics and text are shown on the same page. For example, in the Jeppesen chart for Frankfurt, Germany, a routing strip is shown on the graphic page. The routing strip is a text description of the path, listing the waypoints and constraints in order. This text format may be well suited for cross-checking the procedure constraints with the flight deck CDU.

On FAA charts, the graphics and text are usually shown on separate pages, but there is some variability. FAA STAR charts sometimes have two pages of graphics rather than one. For example, the Houston area STROS TWO arrival procedure has two graphics pages, one for arrival routes and the other for transition routes. The Atlanta HONIE EIGHT arrival has only one graphic page. The FAA Charlotte ADENA THREE arrival chart combines graphic and text all on one page.

Lido departure charts also present the text description of the procedure on a separate page, called the SID Procedure Text (SIDPT). In their electronic product, the Lido/eRouteManual, the text and to-scale graphic depiction can be viewed together on one screen for comparison, with independent zooming on either view. Lido arrival procedures are shown in a graphical depiction only.

There is no data on whether text or graphical depictions of routes are preferred or easier to use. There may be individual differences in pilot preference and performance with the two types of information; some pilots may be more visually oriented and prefer the graphic format while others may be more textually oriented and prefer the text description. Or, it is possible that the text description is easier to understand for some procedures and the graphic description is easier to use for others. These differences have not been studied.

3.1.5 Notes

Arrival and departure charts contain many notes (e.g., altitude, speed, or ATC restrictions, or other procedural or equipment information such as climb gradients). These charts often include text descriptions of the routes, restrictions, or contingency procedures, such as those for lost communications. The notes can be lengthy and repetitive. Many notes do not contain information that is perceived as unusual and important, but they are required based on standards or even legal requirements. Some notes, however, do contain unusual and important information that the pilot may need when making decisions (e.g., when determining whether they are authorized for the procedure). It may be difficult to find the most important notes easily when many non-critical notes are shown. Some examples of low priority notes might be, for example, departure procedure notes that convey information that is already depicted graphically, or notes that inform the pilot of nearby obstacles relevant to a takeoff procedure (e.g., tall trees or structures that affect minimum climb gradients).

Navtech has worked to optimize the actual text of the notes on arrivals and departures, using a brief description with minimal words. Jeppesen attempts to optimize the arrangement and placement of the notes within the graphic page and to number the notes clearly so that their location corresponds to the correct portion of the path.

Lufthansa Systems/Lido also creates a brief description for the note. They also move some types of notes either to the text page of the departure description or to a separate text page for the airport, called the Airport Operational Information (AOI) page. All lost communication procedures and flight planning relevant information is on the AOI page. Lost communication notes were moved because they are rarely needed. Other notes related to airport information that may be required for flight preparation prior to departure were also moved to the AOI page to reduce chart clutter.

3.1.6 Standardized/Optimized Formats

Approach procedures are depicted on a standard one-page format. A strip along the top lists communication frequencies and information that is briefed amongst crewmembers before beginning the approach. The plan view is in the middle of the page. The bottom of the page shows a profile view of the last part of the approach and a table of landing minimums. On FAA approach charts, there is also an airport sketch on the lower portion of the page. This one-page approach chart format was refined in the mid-1990's through multiple research studies (e.g., Osborne, Huntley, Turner, Donovan, 1995; Blomberg, Bishop, and Hamilton, 1995; Wright and Barlow, 1995; Ricks, Jonsson, & Barry, 1996).

The formats for departure and arrival procedures are not standardized in the same way that approach charts are standardized. There is more variability in the geometry for arrival and departure procedures, making their depiction more difficult to standardize. The geometry of arrivals and departures varies, for example, in the length of the different flight paths and the spatial arrangement of the paths and fixes. The result is that text notes and other non-spatial information are placed wherever space is available and the graphical depiction is often drawn not-to-scale. Some manufacturers do standardize the format of departure and arrival procedure more than others, but formats across chart manufacturers may vary considerably. The lack of a standard format is likely to increase information retrieval time for pilots because, unlike standardized approach charts, they do not know in advance where to look for particular types of information. It likely also affects how pilots brief arrival and departure procedures. However, there is no data on these points.

Arrival and departure procedures also do not show a graphical depiction of the altitudes to be flown (i.e., they have no "profile view"). In fact, it is difficult to develop a graphical depiction of altitudes on arrival and departures. One reason for this difficulty is that there may be many different types of altitudes displayed on arrivals and departures (e.g., altitude constraints such as at or above/below, window altitudes, minimum en route altitudes, ATC procedure altitudes, obstacle clearance altitudes). Because the vertical profile for an approach is designed to avoid obstacles first and foremost, they generally only show obstacle clearance altitudes. In contrast, altitude profiles for arrivals and departures are designed with an emphasis on compliance with ATC procedure (e.g., for traffic flow management), and obstacle clearance is a secondary constraint.

Arrival and departure charts also differ noticeably from approach charts in the number of flight paths that are shown, and the number of origins, destinations, and common segments. Approach charts, for example, only show paths that converge toward one runway end. While there may be different initial and intermediate fixes, eventually all the paths have one or more common segments near the runway on an approach procedure. In contrast, arrival and departure charts often begin (or end) at more than one runway end, or other airspace fix. For example, an arrival can depict paths into more than one airport on the same procedure. Accordingly, arrivals and departures depict numerous paths, between different origins and end points. The different paths typically have a runway transition segment, a common segment, and a transition segment to (or from) the en route airspace. This increases the amount of information in the procedure, and requires a correspondingly more visually complex depiction that is difficult to standardize. In an electronic chart product, there may be dynamic ways of highlighting the paths of interest. For example, the Lido/eRouteManual allows the user to highlight a specific flight path by reducing the contrast of the flight paths that are not of interest.

3.1.7 Paper Size

Paper charts may be provided to pilots as bound booklets, loose leafs in a binder, or as individual hard copies printed by the pilot as needed. Most paper aeronautical charts are roughly half the size of a standard 8 ½" x 11" paper, i.e., approximately 5" x 8". Although there does not appear to have been any particular scientific basis for this size choice, it has worked well for years in a confined flight deck space.

In recent years, other chart sizes have been developed. Lufthansa Systems/Lido charts, for example, are larger than US government charts. Lido/eRouteManual charts are printed on standard A4 or A5 paper, and can be on an A5 sheet with a foldout if and when required. Jeppesen also has the ability to use a larger foldout paper format that is twice the size of the standard chart (i.e., a full size standard US sheet of paper). Jeppesen and Lido both use foldout charts for complex depictions such as the Boise procedures, where the extra space can be used to improve the clarity of the information (e.g., by changing the scale to improve readability of flight path). Although fold out charts are helpful for reference and planning, they are more difficult to use in practice during a flight because they take up more space and have to be folded and unfolded manually.

3.1.8 Locations of Interest

Locations areas of interest are sometimes marked on charts for a specific purpose. For example, hotspots denote locations on the airport surface where there is potential for, or a history of, runway incursions; it may be helpful for pilots to be aware of these areas as they traverse the airport surface. Jeppesen uses magenta circles and text labels to indicate hotspots on the airport taxi diagrams. The circle helps to direct the pilot's attention to the location. Arrows, boxes, or insets that zoom in on the area could also be used for the same purpose.

When a location is called out on the chart it is important that its definition and its indicator (i.e., circle, arrow etc.) are clear and consistent. If there is more than one type of location of interest, distinct indicators may be needed to clearly associate the location with its definition.

3.2 Separating Information Across Pages

As mentioned earlier, departure and arrival procedure information on FAA charts is separated; there is one page for the graphical depiction and the other page for a text description of the route. However, these two pages are generally redundant in terms of routing descriptions; all the information required for the procedure is shown on both the text and the graphic page.

There are, however, cases where non-redundant information is separated across pages. For example, there are some arrival procedures where the graphical depiction is separated into two pages. One example of this is the FAA chart for the CURSO TWO RNAV arrival into Miami, Florida. Another example of this is the London Gatwick procedure mentioned in Table 1, where the approach procedure is separated into an Initial Approach page and a Final Approach page.

One advantage of separating information across pages is that when procedures with closely spaced waypoints are separated across pages, the pages can be drawn at different (more appropriate) scales, enhancing readability. Jeppesen did this for the RNAV (RNP) approaches into Boise. Lufthansa Systems/Lido also used different scales for these procedures, but in a slightly different way, where the two different scales are shown side by side instead of on different pages.

When an approach procedure with multiple intermediate fix segments and transitions is separated across pages, another advantage is that information (e.g., a note) that is specific to a path is only depicted when necessary, which eliminates information that is not needed for that path, and reduces the amount of information in the depiction. In addition, when paths that would cross or be very closely positioned together can be separated across pages, visual complexity can be reduced and readability can be improved.

There are drawbacks to separating chart information across pages. In particular, separating information across charts and pages increases the number of charts and pages to retrieve and manage. In the case of printed charts, separating information creates additional paper to carry. The increased number of images (and paper) is a drawback from multiple perspectives; it takes longer to find the correct chart, it increases the cost of production for chart manufacturers, and it results in increased weight when carrying paper charts on to the flight deck. There are also chart-naming and cross-referencing issues because each piece of paper may need a unique title or specific reference name.

3.3 Removing Information

Removing information is the least preferred option for paper charts. In many cases, removal of information is simply not possible or advisable due to a legal requirement to provide and represent a government's procedure source in its entirety.

In some cases, the content and depiction of particular procedures may be customized to suit the specific requirements or needs of an operator or airline based on aircraft type, crew training, or aircraft equipment. For example, Lufthansa Systems/Lido charts are customized for airline operations; the Lido chart does not show information that is only required for lower speed aircraft, for example, in the table of landing minimums for approaches. Jeppesen offers an airline-only version of its charts that also simplifies content to some extent.

With electronic data driven charts, removing information may be a commonly used option. It may be straightforward to configure an electronic display for specific uses. An industry recommendation document (SAE, 2004) provides guidance on what chart elements could potentially be removed, and when, on electronic data driven charts.

4 Assessment of Procedure Attributes

RNAV (RNP) AR approaches, RNAV SIDs, and RNAV STARs were analyzed in an attempt to identify attributes that are associated with procedures that are more difficult to use.

The method used for this review is described in Section 4.1 below. Information about how specific procedures were selected for the review and results of the analyses and are given in Sections 4.2, 4.3, and 4.4 which address Approaches, SIDs, and STARs respectively. Directions for further exploration are provided in Section 4.5.

4.1 Method

We were interested to know whether any objective parameters of a procedure were correlated with difficulty of use. We compared two sets of RNAV and RNAV (RNP) procedures for this analysis. One set of procedures was selected from those with operational issues noted in the most recent ASRS review (Butchibabu et al., 2010) or were highlighted by subject matter experts as being unusually complex; these were placed in the “Problematic” set. The second set of charts, labeled “Baseline,” consisted of RNAV and RNAV (RNP) procedures from the Operational Evolution Partnership (OEP) airports (a set of 35 commercial airports in the US with significant activity) that did not appear in the Problematic set. The specific criteria for procedure selection are detailed below. The final set of procedures in the analysis includes 63 approaches, 52 SIDs, and 54 STARs. A list of these procedures and the airports they are from is provided in Appendix A.

FAA charts were used for this analysis because they are publicly available and easily obtained online. Although the charts differ between manufacturers in terms of their graphic design, all of them represent the same procedure design, so we expect that the underlying complexity of the procedure will be highly correlated across the different manufacturer versions. All selected procedures were current as of 12 January 2012.

We recorded different information for the different types of procedures. The elements that we recorded are listed in Table 2 below. All of these elements that we analyzed are numeric variables; they are either distances or a count of how many times a given element appears. The items in bold in Table 2 provide identification information only and were not analyzed per se. Notice that some information was recorded for the procedure as a whole (e.g., number of IFs in the approach), but other information was recorded separately for each flight path depicted (e.g., number of speed restrictions per path shown on a SID). Window altitudes on SIDs and STARs were recorded as one ‘At or Above’ altitude *and* one ‘At or Below’ altitude. Data samples for each type of procedure are provided in Appendix B. A summary table of data for each airport in the review is also provided in Appendix B. The summary table provides average data for the airport across all the procedures from that airport.

Table 2 Elements recorded by type of procedure.

Approaches 11 Data Elements Total	SIDs 10 Data Elements Total	STARs 12 Data Elements Total
Airport Name* **Procedure Name***	**Airport Name*** **Procedure Name***	**Airport Name*** **Procedure Name***
Number of IAFs (equal to Number of Flight Paths)	Number of Flight Paths	Number of Flight Paths
Number of IFs	**Flight Path Names (Runways)***	**Flight Path Names (Transitions)***
Number of Segments in the Missed Approach Procedure (MAP)	Number of 'At or Above' Altitudes per Path	Number of 'At or Above' Altitudes per Path
Number of RF legs in MAP	Number of 'Mandatory' Altitudes per Path	Number of 'Mandatory' Altitudes per Path
IAF Names (Transitions)*	Number of 'At or Below' Altitudes per Path	Number of 'At or Below' Altitudes per Path
Number of Waypoints from IAF to Runway	Number of Minimum En route Altitudes (MEA) per Path	Number of MEAs per Path
Number of Waypoints Between IF and FAF (equal to number of path segments between IF and FAF)	Number of Minimum Obstacle Clearance Altitudes (MOCA) per Path	Number of MOCAs per Path
Number of RF legs from IAF to Runway	Number of 'ATC Expect' Altitudes per Path	Number of 'ATC Expect' Altitudes per Path
Distance from IF to FAF	Number of Speed Restrictions per Path	Number of Speed Restrictions per Path
Number of Waypoints Between FAF and Runway	Total Distance per Path	Total Distance per Path
Distance from FAF to Runway	Mean Distance Between Waypoints per Path	Mean Distance Between Waypoints per Path
Number of Altitude Constraints		Number of Path Segments
Starting Point for Vertical Profile for each Transition*		Number of Holding Points per Path

*For information only. Not analyzed.

4.2 Approach Procedures

4.2.1 Selection

A total of 63 RNAV (RNP) AR approach procedures from 18 airports were analyzed, six Problematic and twelve Baseline. The list of airports analyzed is shown in Table 3 and the individual procedures names within each airport are shown in Appendix A. The Problematic set was selected based on a list of issues from the PARC RNP Charting Action Team, which focused on approach procedures at locations such as Boise, Idaho and Raleigh-Durham, North Carolina.[3] The ASRS analysis (Butchibabu et al., 2010) was not a source for selecting approach procedures because few approach procedures were found in that data. None of our Problematic approach procedures came from the OEP airport list; they are all from smaller airports, often with terrain in the area.

[3] Raleigh-Durham was not included in our Problematic set because it was simplified as a result of the PARC RNP Working group recommendations. The changes took effect before our analysis was performed.

Table 3. Airports analyzed for approach procedures.

Airports with Problematic Approaches (6)	Airports with Baseline Approaches (12)
Boise (BOI)	Atlanta (ATL)
Bozeman (BZN)	Baltimore-Washington (BWI)
Lewiston (LWS)	Cincinnati-Covington (CVG)
Palm Springs (PSP)	Washington National (DCA)
Rifle (RIL)	Dallas-Fort Worth (DFW)
Scottsdale (SDL)	Washington Dulles (IAD)
	Fort Lauderdale (FLL)
	La Guardia (LGA)
	Chicago Midway (MDW)
	Miami (MIA)
	San Francisco (SFO)
	Tampa (TPA)

4.2.2 Results

There were three statistically significant differences between the Problematic and Baseline sets of approach procedures. First, the Problematic set had more *flight paths*, 4.1 paths on average for the Problematic set versus 1.6 for the Baseline set ($t_{16} = 3.37, p < 0.01$). In other words, Problematic approach procedures have more IAFs and IFs, meaning that there more points from which the aircraft can enter the approach and correspondingly more paths depicted in the plan view of the chart. The flexibility added by multiple IAFs and IFs is related to an increase in the number of flight paths shown, which is related to the increased number of visual elements on the chart. This relates to the high density of visual information of the plan view, because the size of the plan view is fixed (unless the size of the paper is increased).

Our second finding was that the Problematic set had more *path segments* than the Baseline set, with an average of 6.33 waypoints per path compared to 3.8 waypoints per path for the Baseline group ($t_{16} = 6.84, p < 0.01$). This means that there are more heading, distance, and/or altitude changes on these paths, since waypoints are placed where these changes occur. Pilot workload could be increased if they are monitoring every change at these additional waypoints.

Finally, Problematic approach procedures had more *RF legs* than less complex approaches. On average, the Problematic set had 3.7 RF legs per path, while the Baseline group had 0.4 RF legs per path ($t_{16} = 4.4, p < 0.01$).

None of the seven other elements that we analyzed differed significantly between the Problematic and Baseline approach procedures.

4.3 SID Procedures

4.3.1 Selection

A total of 52 RNAV SIDs from 21 airports (10 Problematic and 11 Baseline) were analyzed. The list of airports analyzed is given in Table 4 and the individual procedure names at each airport are shown in Appendix A. The Problematic set was identified based on results from an analysis of ASRS reports for RNAV procedures (Butchibabu, et al., 2010). The Baseline set consisted of two randomly selected RNAV SIDs from OEP airports that were not in the Problematic group.

Table 4. Airports in the SID analysis.

Airports with Problematic SIDs (10)	Airports with Baseline SIDs (11)
Atlanta (ATL)	Cleveland-Hopkins (CLE)
Boston (BOS)	Cincinnati-Covington (CVG)
Baltimore/Washington (BWI)	Newark (EWR)
Dallas-Fort Worth (DFW)	Fort Lauderdale (FLL)
Washington Dulles (IAD)	Dallas-Fort Worth (DFW)
Las Vegas (LAS)	George Bush Intercontinental/Houston (IAH)
Los Angeles (LAX)	John F. Kennedy (JFK)
Miami (MIA)	La Guardia (LGA)
Seattle (SEA)	Phoenix (PHX)
Salt Lake City (SLC)	San Diego (SAN)
	Tampa (TPA)

4.3.2 Results

For departure procedures, the Problematic set had more *flight paths* ($t_{19} = 2.12, p < 0.05$). The average number of flight paths is significantly higher for the Problematic set (approximately 14.4) than for the Baseline set (approximately 5.0).

In our analysis, the number of flight paths is the number of possible path *combinations* an airplane can fly based on the number of entry and exit points in that procedure. This may not necessarily be the number of paths graphically depicted on the page. For example, the LEETZ TWO departure at SLC shown in Figure 7 depicts five paths to the final transitions (exit points). However, because there are three initial runway end points (start points) for the procedure, we recorded 15 flight paths. The number of flight paths for each airport in the data set is given in Appendix B.

None of the other variables that we analyzed differed significantly between the Problematic and Baseline sets.

4.4 STAR Procedures

4.4.1 Selection

A total of 54 arrival procedures were analyzed for 24 airports (13 Problematic and 11 Baseline). The list of airports analyzed is shown in Table 5. The same process used to select SIDs was used for arrival procedures. The full list of procedures is in Appendix A.

4.4.2 Results

Unlike approaches and SIDs, the number of flight paths was not a factor for STARs in this analysis. For STARs, the Problematic set had significantly more *total altitude constraints* ($t_{22} = 3.07, p < 0.01$) and *path segments* ($t_{22} = 3.60, p < 0.01$). In this analysis the *total altitude constraint* variable was the sum of all the different types of altitude constraints recorded, including 'at or above,' 'at or below,' and mandatory altitudes. Window altitudes were recorded as two separate constraints, one 'at or above' and the other 'at or below.' The average number of total altitude constraints was 3.56 for the Problematic set and 0.67 for the Baseline set. This result may be largely driven by the increase in the number of mandatory altitudes for the Problematic set (average of 2.74) compared to the Baseline set (average of 0.13) ($t_{22} = 3.25, p < 0.01$) as seen in the summary data table for STARs in Appendix B.

Table 5. Airports in the STAR analysis.

Airports with Problematic STARs (13)	Airports with Baseline STARS (11)
Atlanta (ATL)	Cincinnati-Covington (CVG)
Boston (BOS)	Houston (HOU)
Baltimore/Washington (BWI)	Newark (EWR)
Charlotte (CLT)	John F. Kennedy (JFK)
Washington National (DCA)	Orlando (MCO)
George Bush Intercontinental/Houston (IAH)	Memphis (MEM)
Washington Dulles (IAD)	West Palm Beach (PBI)
Las Vegas (LAS)	Pittsburg (PIT)
Chicago (ORD)	San Diego (SAN)
Philadelphia (PHL)	San Francisco (SFO)
Phoenix Sky Harbor (PHX)	Tampa (TPA)
Salt Lake City (SLC)	
Teterboro (TEB)	

However, the average number of 'ATC Expect' Altitudes was significantly higher for the Baseline set, contrary to the results seen for the total number of altitude constraints. The average number of 'ATC Expect' Altitudes was approximately 1.83 for the Baseline group and approximately 0.60 for the Problematic group (t_{22}= 3.23, $p < 0.01$).

Finally, STARs in the Problematic set have significantly more *path segments* than the STARs in the Baseline set. The average number of path segments is 11.4 for the Problematic set and 8.6 for the Baseline set (t_{22} = 3.60, $p < 0.01$).

None of the other variables we analyzed for STARs differed significantly between the Problematic and Baseline sets.

4.5 Directions for Further Exploration

The analysis of procedure attributes helped to identify which ones are related to difficulty of use, such as the number of flight paths on approaches and SIDs, and the total number of altitude constraints on STARs.

One of the general limitations of our analysis is that it was conducted by manually recording procedure parameters from an FAA paper chart. We did not have access to any databases of procedure parameters. Because analysis was done by hand, one chart at a time, it required a significant amount of time and concentration. Errors might have been introduced with this labor-intensive process. Also, the analysis was performed on a specific set of charts from one point in time, but procedures change over time, and it is not easy for us to compare different versions of the same procedure because of the manual effort required.

There is also another, more conceptual, limitation of our analysis method. We recorded parameters for each path on the page separately. This approach is straightforward and it is operationally realistic to the extent that pilots only plan to fly one of the several paths depicted. However, a drawback to this approach is that we essentially assumed that there was no interference of information across the many paths shown on a single graphic page. In other words, our analysis did not capture the potential for errors if the pilot confused information about one path with information about a different path. For example, if there are two paths with different altitude constraints that happen to be closely located, the pilot might read the constraint for the wrong (not flown) path. Our analysis did not record information about such situations and therefore provides no data on this issue.

The frequency of errors related to confusing information between the paths is unknown. There are two difficulties in attempting to explore this issue further. First, the graphic design of the chart could significantly affect what information was confusable, and this would vary between chart manufacturers. Second, examining this type of error rate would require detailed examination of the most visually complex charts. So, analysis requires a different selection of procedures for review and a variety of chart samples from different manufacturers.

During our analysis we also came across some issues that we did not address thoroughly, in order to stay focused on the high-level results. Our subject matter experts had two hypotheses about SID complexity that we were not able to explore fully. One idea concerns altitude constraints, which may also be relevant to STAR procedures. Is it possible that the reason why altitude constraints create difficulty is that they occur close together near the airport, and therefore they are tightly clustered in the graphical depiction? The hypothesis anticipates that most altitude constraints are likely to be given within100 miles or so of the airport. We attempted to address this by examining SIDs. We examined the distance at which the furthest altitude constraint was given. Our evaluation indicated that this was not a problem on the FAA charts because SIDs are not drawn to scale. Thus, areas with many constraints are expanded or exaggerated to show the necessary information and areas without constraints are compressed because there is no additional information to convey. The question that remains is how this issue is handled on SIDs that *are* drawn to scale.

The second hypothesis that we did not fully address concerns pilot expectations during SID procedures. Our subject matter experts pointed out a particular type of SID that they called a "stepped climb." The term refers to procedures with altitude constraints during climb (specifically an "at or below" or mandatory altitude). Pilots do not typically expect to level off while climbing to the assigned en route altitude. These constraints are usually the result of airspace design considerations, where crossing traffic may be at the higher altitude. Subject matter experts suggested that these types of "stepped climb" departures may be problematic because pilots might only look for a constraint at the next immediate waypoint along their path, and may not be aware of level-off constraints at waypoints farther down the flight path; so when they get to the restricted waypoint, they may have already exceeded the limiting altitude constraint. The LEETZ TWO departure at Salt Lake City is an example of this type of procedure (see Figure 7). There are also stepped climbs at Las Vegas, Nevada. We were not able to conduct any specific evaluations of stepped climbs that could either confirm or disconfirm the hypothesis that they are more prone to operational errors.

5 Design and Implementation of Instrument Procedures

The process of developing an instrument flight procedure (IFP) is complex, both in terms of the technical requirements and specifications, and in terms of the coordination required inside and outside the government. Procedure development must accommodate all operators, and it must accommodate noise, environment, and airspace constraints. The processes discussed in this section are the same for PBN and conventional instrument procedures.

A recent report (FAA, 2010b) describes plans to streamline the process for developing and amending instrument flight procedures using lean management techniques to better support NextGen. These planned changes do not affect the general processes that are described in this report. A brief description of these plans is provided in Section 5.1.

Instrument procedures are designed and implemented by the Federal Aviation Administration (FAA) Flight Standards Service Flight Technologies and Procedures Division (AFS-400). Within this organization, there are several groups and individuals involved with procedure design and flight operations criteria/standards and oversight. These groups and their functions are described at a high level on the FAA website (www.faa.gov).

FAA Aeronautical and Navigation (AeroNav) Products (AJV-3) publishes and distributes US government civil aeronautical charts and flight information publications, such as charts for terminal operations and en route operations. FAA AeroNav Products is responsible for developing Instrument Flight Procedures (IFPs), which are basically instrument approaches to runway ends. They are also responsible for developing Obstacle Departure Procedures (ODPs). The charting standards used by FAA AeroNav Products, called the Interagency Air Cartographic Committee (IACC) specifications, are available online at http://aeronav.faa.gov/index.asp?xml=aeronav/iacc/index. Development of approach procedures is described in more detail in Section 5.2 below.

STARs and SIDs are initially developed by Air Traffic, but then reviewed and published by FAA AeroNav Products. The development of STARs and SIDs is described in more detail in Section 5.3 below. Regional variation in procedure design is briefly addressed in Section 5.4 below.

5.1 NavLean Instrument Flight Procedures

As mentioned earlier in Section 1, the FAA has been developing more and more PBN instrument procedures (FAA, 2012a; MITRE CAASD, 2011). As this effort continued, it became clear that the process for creating new procedures was too complicated; new procedures could not be developed as quickly as desired. In response to recommendations from an industry task force (FAA, 2010a), the FAA set up an initiative to identify how the process could be revised to take advantage of new, lean, management strategies. The FAA convened internal working groups to identify areas for improvement in 2010. The final set of recommendations was released in the same year (FAA, 2010b).

A succinct summary of the issues with the current process is provided in the Executive Summary (FAA, 2010b):

> The current IFP development and implementation process is actually a bundle of interconnected, overlapping, and sometimes competing processes. No unique description exists for the current process; however, there is a core process for IFP implementation (request, design and development, approval, implementation, and maintenance) along with several other auxiliary processes (Safety Management System, Operations Approval and Certification, Environmental, and Criteria Development) that intersect with this core process to complete the full life cycle of an IFP. Close examination of the IFP life cycle by the Working Groups revealed a multiplicity of components and processes which have often evolved independently to meet requirements that may or may not be related to IFPs. Those processes are then executed by numerous personnel with varied backgrounds, training, and expertise. The guidance that exists is somewhat fragmented and sometimes incomplete. (p. v and vi).

The report provides 21 key recommendations grouped into nine issues, such as streamlining the process for minor modifications and improving the compatibility between Air Traffic and FAA AeroNav Products software. These recommendations are due to be implemented soon. Although the process will become more efficient, the basic steps mentioned in the excerpt above will still be performed.

5.2 Approach Procedures

Instrument approach procedures (IAPs) are federally mandated under Title 14 CFR Part 97. In other words, instrument approaches are regulatory in nature, and therefore have little flexibility in their design and use. Deviation from an IAP could result in an accident because it is designed to maintain obstacle clearance. Whether or not an accident takes place, pilot deviations from instrument approach procedures are considered a violation of a regulation, which could lead to the loss of his/her license.

IAPs commonly arise from a national initiative, a request made by an operator, or a request made by airport management. To be approved, there must be a "reasonable need" for the production of the new IAP to the aviation public at a civil airport. Examples of reasonable need may be a request from the military, from a certified air carrier, or public need. Public need refers to a benefit of two or more aircraft operators directly related to the commerce of the community.

After a reasonable need is established, an airport evaluation is performed (FAA, 2011b). The airport design must meet several requirements such as minimum runway length, runway lighting, GPS source, altimeter setting source, and communication capability, etc. The airport design evaluation is generally the longest step in the process, particularly if funding is necessary to make improvements to the current airport structure. Once the airport design meets all requirements, the procedure can be developed within a few months.

When the procedure is being designed, FAA AeroNav Products gathers input from the local user groups, which generally include airlines and local Air Traffic, to understand the current traffic flow and the types of flight paths that would be appropriate and useful. IAP developers must adhere to Terminal Instrument Procedure (TERPS) criteria and airspace restrictions (FAA, 2002). With the implementation of RNAV and RNP, and the technology available to modern aircraft, developers must now consider more complex issues such as segment lengths, number of waypoints, and turn radii. To help address these complexities and criteria, IAP developers currently use a high fidelity software tool called Instrument Approach Procedure Automation (IAPA). A new system called Instrument Procedure Development System (IPDS) is currently in development for AeroNav Products.

After a procedure is designed, it is sent to quality assurance staff who verify the procedure and send it to an ARINC coder, who attaches a record number to the new procedure. The procedure then goes back to quality assurance.

Next, the procedure goes through flight inspection for 45 days and is simultaneously posted on the public coordination website titled the "Instrument Flight Procedures Information Gateway" (https://www.faa.gov/air_traffic/flight_info/aeronav/procedures/application/). Instrument approaches are not test flown in aircraft simulators (as are SIDs and STARs). Expert test pilots perform the flight inspection for IAPs in suitable aircraft. During flight inspection, pilots evaluate flyability, signal reception, obstructions, and chart complexity. This is a subjective evaluation; flight test pilots may comment on any aspect of the procedure design, even if there are no violations of criteria. Flight inspection is based on flight experience and subjective workload assessment. The test pilots monitor the FMS, approach chart, and out-the-window view. A recording device is also placed in the plane that records aircraft performance and ensures that the aircraft is receiving all necessary signals along the way.

Finally, after passing flight inspection, the procedure goes through Federal Rulemaking and is posted on the Federal Register for public comment for transmittal for sixty days. If there are no comments from the posting, it is published.

5.3 SID and STAR Procedures

SID and STAR procedures allow controllers to issue one instruction instead of multiple clearances to fly into and out of the terminal airport environment. The charts for SIDs and STARs aid both pilots and controllers by providing a graphical depiction of the Air Traffic clearance. The chart sometimes also has a separate text description (see Section 3.1.4).

Local Air Traffic personnel assist with the design of SID and STAR procedures. These procedures are not regulatory. For example, SIDs and STARs show "expected" altitudes, but controllers can issue another altitude as needed for a particular operation. Air Traffic uses TARGETS and RNAV Pro software to develop these procedures. These software tools are not as high fidelity as the software used to design approaches, but the rules in TARGETS follow the same criteria as for approaches. SIDs and STARs are not posted in the Federal Register, but they are posted on the Instrument Flight Procedures Information Gateway mentioned above, for the same period of time as IAPs. Charting standards for departures and arrivals have a little more flexibility than standards for charting instrument approaches.

SIDs and STARs are generally comprised of three segments: en route transition, common route segment, and runway transitions. For a SID, the runway transition is the first outbound segment. The different runway transitions merge to a common point at which the common segment begins. At the end of the common segment, the procedure may split in different directions to join the en route airspace from different transition points. Some SIDs, such as those at Atlanta, have relatively long runway transitions. Others, such as the Salt Lake City WEVIC TWO (Figure 8), have short runway transition segments and a long common segment.

For STARs, the procedure begins from the en route airspace and transitions into a common segment, finally splitting into different runway transitions to align with the different approach paths. A single STAR may provide access to more than one airport if there they are co-located and coordinate the airspace.

SID and STAR procedures are processed through a service group made up of Regional Airspace Procedures Team (RAPT) and Flight Procedures Team (FPT). This service group decides the priority of the procedure and then sends it to AeroNav Products. The coordination process with SIDs and STARs is usually with the same group that identified the need for the procedure. Once a graphical depiction has been sent to AeroNav Products, they check the route, complete the documentation, and repeat the quality assurance check.

Pilot deviations from SIDs and STARS are handled differently from deviations from an instrument approach procedure. Pilots have the option of declining a departure or arrival procedure given to them by air traffic and requesting an alternate clearance. While deviation from a SID or STAR is likely to be reported by ATC because there may be conflicting traffic in the vicinity, obstacle clearance is not the limiting factor.

5.4 Regional Variation in Procedure Design

Procedures are not designed in the same manner throughout the world or the US, even though they are developed with similar criteria and via common processes. Charting manufacturers point out that charting solutions to procedural complexities are affected by the culture of the local area. For example, the FAA uses Terminal Instrument Procedures (TERPS) 8260 criteria (FAA, 2002), while the international community uses Procedures for Air Navigation Products-Aircraft Operations (PANS-OPS) (ICAO, 2006). These differences can be seen between charts produced by the Jeppesen offices in Frankfurt, Germany and the Jeppesen offices in the US.

Procedure design philosophy also varies between the East and West Coasts of the US, based on geography, airspace, and requests from the main operators in the area. This regional variation also makes it more difficult to locate trends and patterns across charts.

6 Summary and Areas for Future Research

This report provides background information on several aspects of charting RNAV and RNAV (RNP) procedures from a human factors perspective. This research area is one of many human factors topics associated with the implementation and PBN. Other related topics are discussed in a draft multi-year plan developed by the Volpe Center for the NextGen Human Factors Division (ANG-C1) in support of the FAA Aviation Safety Line of Business. The overall goal of the project is to evaluate information and depiction of RNAV and RNAV (RNP) procedure charts to improve usability for all operators. This report documents our progress in understanding the issues associated with charting these procedures.

We first discussed charting challenges and options to understand how these procedures are being depicted today. Some of the new strategies include use of tables on charts, separating information across pages, use of insets and varied scales, and use of numbering to clarify what information is related.

Next we presented a review of several approach, arrival, and departure procedures. This review was conducted to systematically understand the features of RNAV and RNAV (RNP) procedures that are associated with visual complexity and difficulty of use. We found that the more difficult instrument approach charts depict procedures with more flight paths, path segments, and radius-to-fix legs. SID procedures that are more difficult show more flight paths. STAR procedures that are more difficult have more total altitude constraints and path segments.

Finally, we provided an overview of the process whereby instrument procedures are designed and implemented, so that we have an understanding of all the steps and criteria used in that process. This process will become more efficient as new lean management strategies are implemented, but the basic steps remain the same.

There are many inter-related human factors research questions that could be considered for future research. For example:

a) How should charts be designed for compatibility with flight deck systems?

b) Does separating procedure information across chart pages provide an overall benefit or not?

c) What is the best layout for a typical use of the information on an arrival and departure chart? What recommendations can be made to help standardize their formats?

d) Are there good alternative formats for depicting constraints on arrivals and departure? Which format works best?

e) Is it acceptable to show a reduced segment of the vertical profile on an RNAV (RNP) approach procedure when necessary due to multiple vertical profiles from differently intermediate fix segments? Would this be acceptable in a non-AR situation?

f) How are the various charting/design options affected by the type of pilot and operations (e.g., corporate versus air transport versus light general aviation operations)?

By addressing these questions, we can develop design recommendations to improve the design of charts so that there is a reduced likelihood of errors by the flight crew. Results of the research could also be used by the FAA to develop human factors guidelines regarding procedure design and depiction. These guidelines will aid in the successful implementation of performance based operations.

7 References

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Appendix A: Procedures Analyzed

Approaches (63)

Problematic Group (18)

Boise (BOI)
RNAV (RNP) Z RWY 10L
RNAV (RNP) Z RWY 10R
RNAV (RNP) Z RWY 28L
RNAV (RNP) Z RWY 28R

Bozeman (BZN)
RNAV (RNP) Z RWY 12
RNAV (RNP) RWY 30

Lewiston (LWS)
RNAV (RNP) RWY 30
RNAV (RNP) Z RWY 8
RNAV (RNP) Z RWY 12
RNAV (RNP) Z RWY 26

Palm Springs (PSP)
RNAV (RNP) Y RWY 13R
RNAV (RNP) Y RWY 31L
RNAV (RNP) Z RWY 13R

Rifle (RIL)
RNAV (RNP) Z RWY 8
RNAV (RNP) Y RWY 26

Scottsdale (SDL)
RNAV (RNP) RWY 21
RNAV (RNP) Y RWY 3
RNAV (RNP) Z RWY 3

Baseline Group (45)

Atlanta (ATL)
RNAV (RNP) Z RWY 8L
RNAV (RNP) Z RWY 8R
RNAV (RNP) Z RWY 9L
RNAV (RNP) Z RWY 9R
RNAV (RNP) Z RWY 10
RNAV (RNP) Z RWY 26L
RNAV (RNP) Z RWY 26R
RNAV (RNP) Z RWY 27L
RNAV (RNP) Z RWY 27R
RNAV (RNP) Z RWY 28

Baltimore-Washington (BWI)
RNAV (RNP) Z RWY 10
RNAV (RNP) Z RWY 15R
RNAV (RNP) Z RWY 28
RNAV (RNP) Z RWY 33L

Cincinnati-Covington (CVG)
RNAV (RNP) Z RWY 18C
RNAV (RNP) Z RWY 18L
RNAV (RNP) Z RWY 18R
RNAV (RNP) Z RWY 27
RNAV (RNP) Z RWY 36C
RNAV (RNP) Z RWY 36L
RNAV (RNP) Z RWY 36R
RNAV (RNP) Z RWY 9

Washington National (DCA)
RNAV (RNP) RWY 19
RNAV (RNP) RWY 1

Dallas-Fort Worth (DFW)
RNAV (RNP) Z RWY 13R
RNAV (RNP) Z RWY 31L
RNAV (RNP) Z RWY 31R

Washington Dulles (IAD)
RNAV (RNP) Z RWY 1R
RNAV (RNP) Z RWY 1C
RNAV (RNP) Z RWY 19L
RNAV (RNP) Z RWY 19C

Fort Lauderdale (FLL)
RNAV (RNP) Y RWY 09L
RNAV (RNP) Z RWY 09R
RNAV (RNP) Z RWY 27R

La Guardia (LGA)
RNAV (RNP) Z RWY 22
RNAV (RNP) Z RWY 04

Chicago Midway (MDW)
RNAV (RNP) Y RWY 13C

Miami (MIA)
RNAV (RNP) Y RWY 08R
RNAV (RNP) Y RWY 12
RNAV (RNP) Y RWY 26L
RNAV (RNP) Y RWY 27
RNAV (RNP) Y RWY 30

San Francisco (SFO)
RNAV (RNP) Y RWY 28R
RNAV (RNP) Y RWY 10R

Tampa (TPA)
RNAV (RNP) Y RWY 19L

Departures (52)

Problematic Group (37)

Atlanta (ATL)
DAWGS FIVE
BRAVS SIX
CADIT SIX
COKEM FIVE
DOOLY FIVE
GEETK SIX

Boston (BOS)
WYLYY ONE

Baltimore/Washington (BWI)
TERPZ TWO

Dallas-Fort Worth (DFW)
NOBLY THREE
TRISS THREE
CEOLA FOUR
DARTZ THREE
FERRA FOUR
AKUNA THREE
CLARE TWO
JASPA TWO
LOWGN THREE
NELYN TWO
PODDE THREE
SLOTT THREE
SOLDO TWO
ARDIA THREE
BLECO TWO
GRABE THREE

Washington Dulles (IAD)
STOIC TWO

Las Vegas (LAS)
BOACH FOUR
COWBY FOUR
PRFUM TWO
SHEAD SEVEN
STAAV FOUR
TRALR FOUR

Los Angeles (LAX)
HOLTZ NINE

Miami (MIA)
WINCO ONE

Seattle (SEA)
HAROB THREE

Salt Lake City (SLC)
WEVIC TWO
LEETZ TWO
PECOP TWO

Baseline Group (15)

Cleveland-Hopkins (CLE)
ALPHE THREE

Cincinnati-Covington (CVG)
BNGLE THREE
HAGOL THREE

Newark (EWR)
PORTT TWO

Fort Lauderdale (FLL)
BAHMA TWO
THNDR ONE

George Bush Intercontinental/Houston (IAH)
GUSTI ONE

John F. Kennedy (JFK)
SKORR THREE

La Guardia (LGA)
NTHNS ONE
TREEO ONE

Phoenix (PHX)
BARGN ONE
SMALL ONE

San Diego (SAN)
POGGI TWO

Tampa (TPA)
BAYPO FOUR
GANDY FOUR

Arrivals (54)

Problematic Group (34)

Atlanta (ATL)
HONIE EIGHT
CANUK ONE
ERLIN NINE
FLCON SEVEN
HERKO SIX
PEECHY SEVEN

Boston (BOS)
KRANN ONE

Baltimore-Washington (BWI)
RAVNN THREE

Charlotte (CLT)
SUDSY FOUR
HUSTN TWO
JOHNS THREE
ADENA THREE

Washington National (DCA)
ELDEE FIVE

George Bush Intercontinental/Houston (IAH)
TXMEX ONE
ROKIT ONE

Washington Dulles (IAD)
BARIN ONE
SHANON TWO

Las Vegas (LAS)
GRNPA ONE
KEPEC TWO
TYSSN THREE
SUNST TWO

Chicago (ORD)
ROYKO THREE

Philadelphia (PHL)
GUNNI TWO

Phoenix Sky Harbor (PHX)
GEELA FIVE
KOOLY FOUR
MAIER FIVE
EAGUL FIVE

Salt Lake City (SLC)
SKEES THREE
QWENN THREE
NORDK THREE
LEEHY THREE
DELTA THREE
BEARR FOUR

Teterboro (TEB)
JAIKE THREE

Baseline Group (20)

Cincinnati-Covington (CVG)
SARGO TWO
TIGRR TWO

Houston (HOU)
COACH ONE
COLUMBIA ONE

Newark (EWR)
PHLBO TWO
FLOSI ONE

John F. Kennedy (JFK)
PARCH ONE

Orlando (MCO)
BAIRN TWO
PIGLT TWO

Memphis (MEM)
BEERT FOUR
TAMMY THREE

West Palm Beach (PBI)
WLACE TWO
FRWAY THREE

Pittsburg (PIT)
DEMME ONE
JESEY ONE

San Diego (SAN)
BAYVU ONE
LYNDI TWO

San Francisco (SFO)
YOSEM ONE

Tampa (TPA)
DADES THREE
DEAKK THREE

Appendix B: Procedure Data Samples and Summaries by Airport.

Table B.1 Approach Procedure Data Samples.

Airport	Boise								Atlanta	Scottsdale
Procedure Name	**RNAV (RNP) Z RWY 28L**								**RNAV (RNP) Z RWY 8L**	**RNAV (RNP) Z RWY 3**
Number of IAFs (equal to Number of Flight Paths)	8								1	1
Number of IFs	5								1	1
Number of Segments in the MAP	1								3	6
Number of RF legs in MAP	0								0	4
IAF names (Transitions)	**RENOL**	**PARMO**	**CADKI**	**UTEGE**	**EREXE**	**CANEK**	**BANGS**	**EMETT**	**OSTRR**	**HAWAI**
Number of Waypoints from IAF to Runway	5	6	6	8	8	7	9	9	4	4
Number of Waypoints Between IF and FAF	3	4	4	5	5	5	5	6	1	1
Number of RF legs from IAF to Runway	1	2	2	1	0	0	2	3	0	1
Distance from IF to FAF	8.5	14.9	14.9	10	10	10	15.6	20.6	6.6	17.8
Number of Waypoints Between FAF and Runway	0	0	0	0	0	0	0	0	0	0
Distance from FAF to Runway	3	3	3	3	3	3	3	3	5.7	5.9
Number of Altitude Constraints	0	0	0	0	0	0	0	0	3	0
Starting Point for Vertical Profile	FAF	FAF	FAF	FAF	FAF	FAF	FAF	FAF	IAF	IF

IAF Initial Approach Fix
IF Intermediate Fix
FAF Final Approach Fix
MAP Missed Approach Procedure

Table B.2. SID Procedure Data Samples.

Airport	Atlanta										Cincinnati-Covington						
Procedure Name	**BRAVS FIVE**										**HAGOL THREE**						
Number of Flight Paths	10										7						
Flight Path Names	**8L**	**8R**	**9L**	**9R**	**10**	**26L**	**26R**	**27 L**	**27 R**	**28**	**18L**	**18C**	**18R**	**27**	**36 R**	**36 C**	**36 L**
Number of 'At or Above' Altitudes	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	0
Number of 'Mandatory' Altitudes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of 'At or below' Altitude	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of MEA	1	1	1	1	1	1	1	1	1	0	2	2	2	2	2	2	2
Number of MOCA	1	1	1	1	1	1	1	1	1	0	2	2	2	2	2	2	2
Number of 'ATC Expect' Altitudes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of Speed Restrictions	0	0	1	1	1	0	0	1	1	1	0	0	0	0	0	0	0
Total Distance	97	97	74	74	76	105	105	82	82	81	100	102	108	86	76	85	84
Mean Distance Between Waypoints	19	19	25	25	19	21	21	41	41	27	13	15	12	22	25	14	14

ATC Air Traffic Control
MEA Minimum En Route Altitude
MOCA Minimum Obstacle Clearance Altitude

Table B.3. STAR Procedure Data Samples.

Airport	Washington National			San Francisco	
Procedure Name	**ELDEE FIVE**			**YOSEM ONE**	
Number of Flight Paths	3			2	
Flight Path Names (Transitions)	**BKW**	**FIMPA**	**SHAAR**	**OAL**	**LIDAT**
Number of 'At or above' Altitudes	1	1	2	0	0
Number of 'Mandatory' Altitudes	4	4	4	0	0
Number of 'At or below' Altitudes	0	0	0	0	0
Number of MEA	6	7	6	4	4
Number of MOCA	0	0	0	0	0
Number of 'ATC expect' Altitudes	2	2	2	3	3
Number of Speed Restrictions	0	0	0	0	0
Total Distance per Path	244	267	145	198	223
Mean Distance Between Waypoints	14.4	15.7	11.2	24.8	27.9
Number of Path Segments	17	17	13	8	8
Number of Holding Points	4	4	3	0	0

Table B.4 Summary Data for Approach Procedures by Airport.

	Airport	Number of IAFs	Number of IFs	Number of Segments in the MAP	Number of RF legs in MAP	Number of Waypoints from IAF to Runway	Number of Waypoints between IF and FAF	Number of RF legs from IAF to Runway	Distance from IF to FAF	Number of Waypoints Between FAF and Runway	Distance from FAF to runway	Number of Altitude Constraints	Starting Point for Vertical Profile
Baseline	ATL	1	1	2.4	0	4.7	1	0	7.1	0	5.2	0	IAF
	BWI	1.25	1	1	0	2.5	0.3	0	6.9	0	4.9	2.5	IF
	CVG	1	1	2	0	4.1	0.9	0	6.7	0	4.6	0	IAF
	DCA	2	2	1	0	3	0	2.5	4.7	2.5	5.3	0	IF
	DFW	0.7	1	1.3	0.7	3.7	1	0	9.3	0	5.4	0	IF
	FLL	2	1	1.7	0	3	0	0	6.2	0	5.8	2	IF
	IAD	2	1	1.5	0	3.5	0	0.5	9.0	0	4.7	0	IF
	LGA	1.5	1	1.5	0	4	0	0.5	7.3	1	4.9	0	IF
	MDW	1	1	2	0	6	2	2	14.9	1	4.2	3	IF
	MIA	2	1	2	0	4.1	1	0	9.3	0	4.9	0.8	IF
	MSP	3	1	2	0	3	0	0	6.8	0	6.5	0	IF
	SFO	1	1	2.5	0.5	4	0	0	5.8	1	5.6	0	IF
	TPA	3	1	2	0	4.3	1	0	8.1	0	6	2	IF
Problematic	BOI	8	5	1.5	0	6.1	2.9	6	11.8	0	3	0	FAF
	BZN	4.5	3.5	2.5	0.5	6.6	4	4.5	13.4	0	3.6	0	FAF
	LWS	3.5	3.5	2.3	0.8	6.4	0.8	2	6.9	0.7	6.4	0	FAF
	PSP	3.7	1	2.3	0.3	6.9	1.3	6	8	0.7	7.4	3.4	IF
	RIL	3.5	1	4	1.5	6	1.5	2.5	10	1	6.8	0	IF
	SDL	1.3	1	5	3	6	0.7	1.3	9.6	0.7	5.7	1.5	IF

Table B.5. Summary Data for SID Procedures by Airport.

	Airport	Number of Flight Paths	Number of *'At or Above'* Altitudes	Number of *'Mandatory'* Altitudes	Number of *'At or Below'* Altitudes	Number of MEA	Number of MOCA	Number of *'ATC Expect'* Altitudes	Number of Speed Restrictions	Total Distance Per Path	Mean Distance Between Waypoints
Baseline	CLE	6	1	0	0	1	1	0	0	121	40.3
	CVG	7	0.6	0	0	2	2	0	0	141.5	25.8
	EWR	8	1	0	0	3	3	0.25	0	41	8.2
	FLL	4.5	1	0	0	0	0	0.5	0.5	69.3	11.6
	IAH	1	0	0	0	4	4	0	0	271	67.8
	JFK	4	2	0	0	1	1	0	1	18	9
	LGA	2.5	3	0	2.5	3.5	3.5	0	2.5	55.5	8.7
	PHX	9	0	0	0	5.8	0	0	0.5	266	31.3
	SAN	2	0	0	2	2	0	0	1	85	17
	TPA	6	1	0	0	3.8	3.8	0	0	131.3	20.2
Problematic	ATL	10	0.7	0	0	1	1	0	0.7	120.0	25.1
	BOS	1	1	0	0	1	1	0	1	11	5.5
	BWI	36	1	0	0	1.7	3.3	0	0.92	55.7	10.1
	DFW	10.5	2.0	0	0	2.8	0	0	1	247.5	44.8
	IAD	28	0	0	0	5.5	5.5	0	0	61.5	11.0
	LAS	13.5	2.5	0.25	0.8	1.8	1.4	0.06	0.2	204.9	31.6
	LAX	4	1	0	2	1	0	0	0	140	21.7
	MIA	8	1	0	0	1	1	0	0.5	52	10.4
	SEA	18	1	0	0	1	1	0	0	119.8	18.5
	SLC	15	2.3	0.25	1	4.0	4.0	0.8	2	204.0	25.6

Table B.6. Summary of STAR Procedures Data by Airport.

	Airport	Number of Flight Paths	Number of *'At or Above'* Altitudes	Number of *'Mandatory'* Altitudes	Number of *'At or Below'* Altitudes	Number of MEA	Number of MOCA	Number of *'ATC Expect'* Altitudes	Number of Speed Restrictions	Total Distance per Path	Mean Distance Between Waypoints	Number of Path Segments	Number of Holding Points
Baseline	CVG	1.5	0.0	0.0	0.0	3.5	0.0	3.0	1.5	278.5	27.9	10.3	3.3
	EWR	13.5	1.5	1.0	0.0	5.8	0.0	1.0	2.0	197.3	16.4	12.0	3.7
	FLL	4.0	0.0	0.0	0.0	5.1	0.0	2.3	1.5	172.4	19.5	8.9	2.1
	HOU	10.0	0.0	0.0	0.0	7.3	0.0	1.0	1.0	222.7	21.3	10.3	1.2
	IAH	11.7	0.0	0.1	0.0	6.2	0.0	1.0	1.1	189.6	26.7	7.3	1.0
	JFK	24.0	0.0	0.0	0.0	5.4	2.7	3.3	0.0	175.2	24.3	7.1	2.7
	MCO	2.5	0.0	0.0	0.0	4.9	0.0	1.5	1.0	126.5	15.3	8.4	1.3
	MEM	4.5	0.0	0.0	0.0	3.6	0.0	2.0	0.0	198.1	23.7	8.3	2.9
	PBI	4.0	0.0	0.0	0.0	5.4	0.0	2.3	0.0	198.7	20.0	9.4	2.4
	SAN	3.0	3.9	0.5	1.0	6.3	4.0	0.5	1.0	108.8	14.9	7.4	0.4
	SFO	2.0	0.0	0.0	0.0	4.0	0.0	3.0	0.0	210.5	26.3	8.0	0.0
	TPA	5.0	0.0	0.0	0.0	3.7	0.0	1.0	0.4	111.9	18.6	6.3	1.5
Problematic	ATL	14.8	1.0	2.3	0.0	3.8	0.0	0.2	1.8	267.1	24.0	11.1	2.7
	BOS	3.0	3.0	5.3	0.0	5.3	0.0	0.0	2.7	191.3	14.1	13.7	1.0
	BWI	6.0	0.5	3.5	0.0	6.5	0.0	1.0	0.0	112.5	12.0	9.5	1.5
	CLT	3.0	0.0	0.0	0.0	4.6	0.0	0.8	0.0	189.7	17.4	11.1	2.8
	DCA	3.0	2.0	4.0	0.0	6.3	0.0	2.0	0.0	218.7	13.7	15.7	3.7
	IAD	10.0	0.0	3.3	0.0	3.3	0.0	1.3	1.0	150.5	15.6	9.5	1.8
	LAS	2.6	0.8	3.5	0.4	4.7	0.0	0.0	3.0	159.2	18.0	9.1	1.5
	ORD	2.0	0.0	0.0	0.0	6.0	0.0	0.0	0.0	178.0	13.7	13.0	2.0
	PHL	6.0	0.0	0.0	0.0	9.2	0.0	0.0	1.0	187.8	19.3	9.7	2.0
	PHX	11.0	1.3	5.8	0.7	8.2	3.8	0.0	5.4	153.4	13.2	11.8	2.9
	SLC	9.7	0.3	2.2	0.0	5.8	0.0	0.8	0.2	203.4	21.0	9.6	2.8
	TEB	5.0	0.0	3.0	0.0	2.0	0.0	1.0	3.0	210.2	15.9	13.2	2.4