Line Pilot Perspectives on Complexity of Terminal Instrument Flight Procedures

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13. ABSTRACT (Maximum 200 words)

Instrument flight procedures (IFPs) based on RNAV and RNP offer safety enhancements along with new levels of flexibility to negotiate terrain, airspace, and environmental considerations. However, operational implementation of performance-based IFPs does not always go smoothly. We gathered input on subjective factors related to IFP and chart complexity by interviewing 45 professional line pilots from major and regional airlines, corporate operators, and an air taxi operator. We observed groups of 2 or 3 pilots (from the same operator, flying the same aircraft) review and brief IFPs as they would normally do, then discussed the IFPs in detail to identify areas of potential confusion about either the IFP or the chart. The primary goal of the study was to identify subjective factors in IFP complexity. The secondary goal was to understand how pilots use charts today, especially for arrivals and departures. Results identified a broad range of issues including IFP design, issues related to both IFP design and charting, and issues that are outside the scope of the IFP design per se, such as crew and operator factors, the use of aircraft automated systems to fly PBN IFPs, and interactions with Air Traffic Control.

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APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
oz	ounces	28.35	grams	g
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
mL	milliliters	0.034	fluid ounces	fl oz
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
g	grams	0.035	ounces	oz
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

Preface and Acknowledgements

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We would like to express our appreciation to Jeppesen, Inc. and Ted Thompson in particular. Jeppesen allowed us access to their aeronautical charts for the Instrument Flight Procedures (IFPs) tested and discussed in this study. Ted patiently answered numerous questions about chart design and production.

FAA Aeronautical Information Services (AJV-5) staff also contributed to this study. Brad Rush, in particular, lent us his broad expertise and history of understanding not just how, but why, aeronautical charts are the way they are.

We also want to acknowledge those who read our study plan in advance and provided us thoughtful input. Among these reviewers were Marc Henegar (Air Line Pilots Association), Lev Prichard (Allied Pilots Association), Brian Townsend (American Airlines), and Michael Gordon-Smith (CMC Electronics).

Recruiting pilots for this study was challenging. We would like to acknowledge the support of the National Business Aviation Association (NBAA), the Regional Airline Association, and the various airlines and operators who participated in the study. Key persons included the administrative support and chief pilot from the operators, and those who put us in contact with the correct people at each operator.

We would like to thank the pilots who participated or even just inquired about participating. We were not able to schedule time with everyone who wanted to voice their thoughts on new IFPs, but we appreciate their interest in the topic and their willingness to talk with us.

We would also like to thank Sam Miller (MITRE) who carefully explained the behavior of the aircraft vertical navigation systems to us and helped us understand our results. A final thanks goes to those who listened to our briefings and provided thoughtful feedback to help clarify and mature our analyses and reports.

Feedback on this document may be sent to Divya Chandra (Divya.Chandra@dot.gov) or Rebecca Markunas (Rebecca.Markunas@dot.gov). Further information on the Instrument Procedures research program is available at http://www.volpe.dot.gov/our-work/safety-management-and-human-factors/human-factors-research-instrument-procedures-faa-nextgen.

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Abbreviations

AC	Advisory Circular
ACF	Aeronautical Charting Forum
AIM	Aeronautical Information Manual
AR	Authorization Required
ASRS	Aviation Safety Reporting System
ATIS	Automated Terminal Information Service
ATC	Air Traffic Control
BOI	Boise, Idaho
BOS	Boston, Massachusetts
CDU	Control and Display Unit
CFR	Code of Federal Regulations
CG	ACF Charting Group
DCA	Washington National, District of Columbia
DEN	Denver, Colorado
DME	Distance Measuring Equipment
D-ATIS	Digital ATIS
EFB	Electronic flight bag
FAA	Federal Aviation Administration
FL	Flight level
FLCH	Flight Level Change
FMS	Flight Management System
FOM	Flight Operations Manual
GA	General Aviation
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IAP	Instrument Approach Procedure
IACC	Interagency Air Cartographic Committee
IFP	Instrument Flight Procedure
ILS	Instrument Landing System
IPG	ACF Instrument Procedures Group
KT(s)	Knot(s)
LGA	La Guardia, New York, New York
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical Guidance

MCP	Mode Control Panel
MEA	Minimum Enroute Altitude
MOCA	Minimum Obstruction Clearance Altitude
MSA	Minimum Safe Altitude
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NM	Nautical mile
OPD	Optimized/Optimum Profile Descent
PDC	Pre-departure clearance
PF	Pilot Flying
PM	Pilot Monitoring (previously known as the "pilot not flying")
PBN	Performance Based Navigation
RF	Radius-to-fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RVR	Runway Visual Range
RWY	Runway
SID	Standard Instrument Departure
SLC	Salt Lake City, Utah
STAR	Standard Terminal Arrival Route
US	United States
VNAV	Vertical Navigation
VOR	Very High Frequency Omnidirectional Range

Executive Summary

Introduction and Background

Navigation technologies such as Area Navigation (RNAV) and Required Navigation Performance (RNP) have spurred a tremendous transformation of the National Airspace System (NAS) in the United States over the past decades. New Performance-Based Navigation (PBN) Instrument Flight Procedures (IFPs) are being developed and implemented at a rapid pace to capture operational efficiencies and to improve safety, particularly for airport approach, arrival, and departure operations. These PBN IFPs are key components of the Next Generation Air Transportation System (NextGen) modernization of the NAS.

This project began as an effort to understand issues in the operational implementation of PBN IFPs in the airport terminal airspace. Specifically, we consider Standard Instrument Departures (SIDs), Standard Terminal Arrival Routes (STARs), and Instrument Approach Procedures (IAPs). Although new IFP designs are vetted carefully through design criteria, software simulations, and flight simulations, operational implementation does not always go smoothly. Shortcomings of new IFPs are often blamed on "human factors," but there are many humans involved and each has his/her own perspective on the difficulties they face. The Volpe Center has conducted analyses and studies to understand the complexity of SIDs, STARs, and IAPs with a focus on the flight crew perspective. The Air Traffic Control (ATC) perspective is also important and should be the focus of a future study.

Earlier we looked at objective measures of IFP complexity (Chandra, Grayhem, and Butchibabu, 2012). We also collected data on the visual complexity of aeronautical charts that depict IFPs, in terms of the time required to find specific information (Chandra and Grayhem, 2013). Objective measures of IFP complexity are unsatisfactory because they make only gross comparisons between IFPs. Visual complexity of charts is only one aspect of overall IFP and chart complexity.

In this study, we examine IFPs from the viewpoint of *subjective complexity* for line pilots. We defined a subjective complexity factor as one that requires an extra mental or physical step by the pilot. If the pilots who participated in the study mentioned that they would be especially aware under certain circumstances, or especially careful, these were our cues that there was subjective complexity.

The primary goal of this study was to gather a comprehensive list of subjective complexity factors related to IFPs that affect the flight crew. The secondary goal of this study was to understand how pilots use charts today within the context of modern flight deck automated systems.

Method and Participants

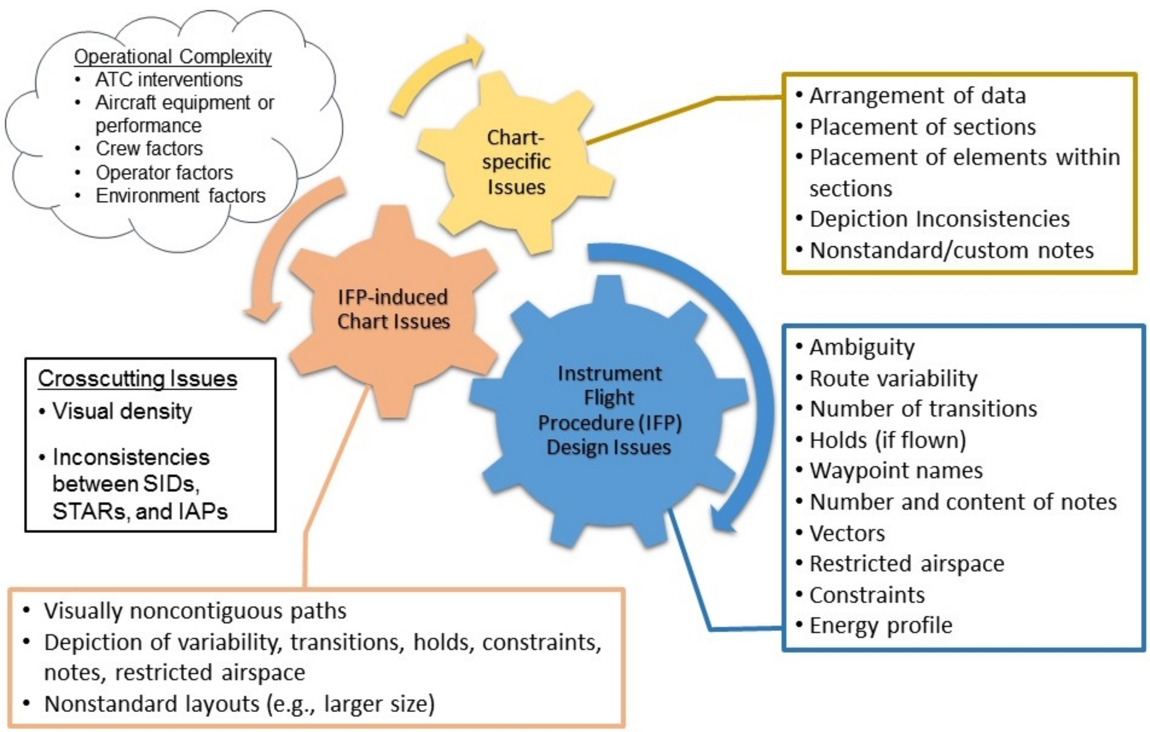
We gathered input from 45 professional line pilots from major and regional airlines, corporate operators, and an air taxi operator. We observed groups of 2 or 3 pilots (from the same operator, flying the same aircraft) review and brief IFPs to each other as they would normally do, then discussed the IFPs in detail to identify areas of potential confusion about either the IFP or the chart. Each group of participants reviewed two SIDs, two STARs, and two IAPs. The participants flew a variety of aircraft, with different types of automated systems to aid them.

The study was conducted in a meeting room, not in front of an aircraft simulator. This had the advantage of allowing participants to focus on the IFP and chart, rather than on real-time flying tasks. Participants used charts from Jeppesen in the study, which were familiar to them from regular use.

Results

Results identified a broad range of issues including IFP design, issues related to both IFP design and charting, and issues that are outside the scope of the IFP design per se, such as crew and operator factors, the use of aircraft automated systems to fly PBN IFPs, and interactions with ATC. Specific examples of each issue are provided in this detailed report.

We organized the issues into a subjective complexity framework to help IFP designers understand the sources of IFP and chart complexity and how they are interrelated (see figure below). IFP design issues are the biggest driver (as indicated by the largest gear in the framework). They can induce issues with the overall chart design, which in turn can affect chart-specific issues. We used the framework to develop recommendations on how to reduce subjective complexity. It could also be used to anticipate potential IFP design complexities. As shown in the figure, we separated issues that are outside the control of IFP and chart designers, which we call "operational complexity." Operational complexity includes factors such as ATC interventions, aircraft-specific issues, crew factors, operator factors, and environmental factors, such as weather. Two cross-cutting issues were also identified, visual density (which naturally arises in airspace with many routes and high density operations), and inconsistencies between the different types of IFPs.



Our findings also address how participants reviewed and briefed IFPs and charts to understand how they familiarize themselves with IFPs and how they would handle any confusion or difficulties. So, a secondary result of this study is an improved understanding of how charts are used in normal operations in the context of modern flight deck systems. This knowledge may be helpful in identifying areas for improvement in chart depictions and may contribute to guidance for future data-driven terminal charts.

Summary of Recommendations

After presenting results of the study and discussing their interpretation, we present recommendations for stakeholders in the design and use of IFPs and their chart depictions. Below is a summary of these recommendations; additional context and supporting evidence are provided in the full report.

IFP Design Recommendations

- Minimize flight path constraints.

- Minimize flight path transitions.
- Ensure that energy profiles are smooth between adjoining IFPs and/or segments of IFPs.
- Waypoint names should be pronounceable, short (with few syllables), and, ideally, familiar.
- Minimize and prioritize notes.

Recommendations Related to Operational Complexity

- IFP designers should assume that one or more operational complexity factors will affect normal operations.
- IFP designers should be better informed about aircraft equipment variation and flight deck tasks and perspectives.
- The range within which runway changes are not allowed should be increased to reduce flight crew workload during arrivals, especially for arrivals into terminal areas with high traffic density or complex arrival routes.

Joint IFP Design and Chart Recommendations

- Develop guidance to decide when to separate flight paths into different IFPs or keep a single IFP.
- Clarify and separate notes based on purpose.
- Reduce the overall number of notes.
- Provide data on SIDs and STARs to give pilots a general sense of the terrain in the terminal area.

Chart Recommendations

- Clearly indicate the “top altitude” on SIDs.
- Carefully place notes.
- Have a clear graphical connection between sections if the flight path is split between chart sections (or pages/images).
- Emphasize information that is nonstandard and of operational importance (e.g., nonstandard altitude and/or speed constraints).

Joint IFP Design and Training Recommendations

- Identify and eliminate ambiguity through training and clearer IFP design principles.
- Improve pilot training and IFP design principles to improve pilot understanding on why IFPs are designed the way they are.

Summary of Key Contributions

We made significant progress in understanding line pilot perspectives on the complexity of IFPs. Our findings can be applied to any type of IFP, PBN or conventional. Key contributions are listed below.

- Defined and separated different types of IFP complexity for line pilots.
- Developed a comprehensive list of subjective complexity factors.
- Identified operational complexity as a separate problem area that cannot be addressed by IFP designers alone.
- Gained a better understanding of how pilots use charts during reviews and briefings.
- Identified several recommendations for design of IFPs and associated charts.
- Identified areas for future research, such as understanding the air traffic controller perspective in IFP design.
- Informed industry and government representatives about this study and its results, so that they can immediately begin to consider the recommendations when designing IFPs.

1 Introduction

The Federal Aviation Administration (FAA) defines an Instrument Flight Procedure (IFP) as "a charted flight path defined by a series of navigation fixes, altitudes, and courses provided with lateral and vertical protection from obstacles from the beginning of the path to a termination point" (FAA Order 8900.1). In other words, IFPs define a published lateral and vertical path from one place to another that clears obstacles along the way. IFPs define turns, climbs, descents, and sometimes even speed, along the flight path. The flight crew must fly the path defined in the IFP when cleared by Air Traffic Control (ATC).

New IFPs enhance safety and efficiency of flight operations through the use of Performance Based Navigation (PBN) (RTCA, 2013). PBN relies upon Area Navigation (RNAV) and Required Navigation Performance (RNP), which provide more accuracy and precision than conventional, ground-based, navigation aids. RNAV Standard Terminal Arrivals Routes (STARs), RNAV Standard Instrument Departures (SIDs) and Instrument Approach Procedures (IAPs) that use RNP are all PBN IFPs. These PBN IFPs are key components of the Next Generation Air Transportation System (NextGen) modernization of the NAS. The FAA tracks use of these PBN IFPs and posts them online at www.faa.gov/nextgen/pbn/dashboard.

IFPs based on RNAV, including those with RNP segments, offer safety enhancements along with greater levels of flexibility to negotiate terrain, airspace, and environmental considerations. New IFPs can increase access to runways, resulting in increased airport capacity. They can also reduce track miles through more efficient designs, leading to reduced fuel consumption and lower carbon emissions.

However, PBN IFPs can also be more "complex" than older IFPs in a number of ways. For example, they can have more strictly defined paths (i.e., more altitude and speed constraints), they can be more precise laterally with RNP, and they may have more route segments and more critical notes. Overall, there is less room for flight crew error along a PBN IFP. As a result, flying tightly defined PBN IFPs typically requires the assistance of a Flight Management System (FMS), and may involve additional crew oversight of other automated systems involved in flight path management. These complexities are not necessarily a direct result of PBN, but may have to do with how PBN is being used in new IFPs.

Charts for PBN IFPs can also look quite different from charts for conventional IFPs, such as an Instrument Landing System (ILS) approach (Chandra, Grayhem, and Butchibabu, 2012). This can result in complexity, in terms of flying the IFP as intended, and difficulty constructing and using a graphic depiction, not just for IAPs, but also for STARs and SIDs.

In summary, PBN IFPs are valuable, but they may impose additional workload on flight crews. Their impact on flight crew workload needs to be understood in order to increase confidence that they will work as intended in actual flight operations. In response to this research need, the FAA sponsored the Volpe Center to examine issues such as the design, depiction, usability, and flyability of IFPs in order to reduce their susceptibility to errors by appropriately qualified pilots.

We first present some additional context for this research. Section 1.1 explains the airspace design goals that IFPs need to achieve. Section 1.2 presents background on related human factors work that has been done to date. Section 1.3 presents an overview of the current study. Section 1.4 provides readers with some insights on how to read this lengthy report. It contains an overview all of the main report sections.

1.1 Airspace Design Goals

As new IFPs are developed and implemented in the field, it is important to keep in mind what we need in the end state. In particular, we must give pilots clear and complete instructions on how to interpret and fly new airport terminal area IFPs. Any restrictions on speed and altitude need to be conveyed clearly. This will require a coordinated effort to ensure both that the IFP is well designed and that the pilot is appropriately trained. New IFP designs need to allow flexibility for operational efficiency, but this should not create undue confusion for the flight crews. New IFP designs must accommodate as many aircraft types as possible. They must also accommodate different types of crews that fly these aircraft and operations with different priorities, different types of flight deck systems, and different levels of ground-based support (e.g., Dispatch, Air Traffic). All of these changes need to consider human performance, workload, and potential for confusion or errors.

Stakeholder viewpoints also need to be considered when developing new IFPs. Stakeholders include:

- IFP designers who develop the flight path instructions;
- Regulators who ensure that the IFP design meets established criteria and specifications;
- Operators who seek particular types of safety and efficiency from the new IFP design;
- Cartographic designers who convert the IFP design into a visual representation, a chart, for use by the flight crew;
- Air Traffic controllers who assign the IFPs to flight crews and confirm their progress along the assigned route;
- Flight crews who fly the IFPs;
- Aircraft-systems designers whose avionics and software are used by flight crews to fly the IFP.

Issues in the design and use of PBN IFPs are among many topics covered in a 2013 report submitted to the FAA by the Performance-based Operations Aviation Rulemaking Committee (PARC)/Commercial Aviation Safety Team (CAST) Flight Deck Automation Working Group, titled "Operational Use of Flight Path Management Systems." (The report is available under the Aircraft Certification section of the FAA website.) Finding 18 in this report addresses "complex and unfamiliar" IFPs that may be developed during airspace design (see pp. 86-89 in the PARC/CAST report). Recommendation 11, which is related to Finding 18, discusses the need for IFP designs for SIDs, STARs, and IAPs to consider complexity and mixed equipage issues.

1.2 Related Human Factors Research

Operational implementation of new IFPs does not always go smoothly even though new designs are vetted carefully through design criteria, software simulations, and flight simulations (e.g., FAA Order 8260.58A, FAA Order 8260.3C, FAA Order 8900.1, FAA Order 7100.41A, and ICAO, 2009). Shortcomings of new IFPs are often blamed on "human factors," but there are many humans involved and each has his/her own perspective on the difficulties they face. For example, IFP designers may think of complexity in terms of parameters such as vertical and lateral flight paths, but pilots—particularly line pilots who fly the IFPs daily in dynamic real world conditions—may think differently about complexity. Line pilots are not trained in IFP design, and their understanding of the aircraft automated systems is not at the level of an expert "technical pilot." Technical pilots are specialists who sometimes participate on IFP design teams, but they do not typically fly on a daily basis.

Human factors considerations for PBN IFPs were first reported systematically by Barhydt and Adams (2006). Their list of issues is comprehensive and has many interrelated topics that cut across different stakeholder groups. Two papers by Barhydt and Adams (2006 and 2007) concluded that there was a need for specific IFP design guidelines that consider the effects of human performance.

Barhydt and Adams (2007) is an analysis of reports from the National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) to understand flight crew issues related to RNAV SIDs and STARs. They found that flight crew issues could be traced back to Air Traffic procedures, airline operations, aircraft systems, instrument procedure design, or some combination of these factors. An updated look at ASRS events related to RNAV operations (Butchibabu, Midkiff, Kendra, Hansman and Chandra, 2010) came to a similar conclusion, that operational issues arise from a combination of factors related to Air Traffic, aircraft equipment, and instrument procedure design. In addition, Butchibabu, et al. grouped IFP design with chart design issues because ASRS narratives do not provide sufficient information to distinguish between IFP and chart design.

Two other studies explored the complexity of PBN IFPs (Chandra, Grayhem, and Butchibabu, 2012; Chandra and Grayhem, 2013). In Chandra et al. (2012), we attempted to quantify IFP complexity objectively. We found that the complexity of a PBN IFP is difficult to measure with only quantifiable parameters. The analysis yielded only general findings that were relatively unsurprising. IFP design parameters that were associated with an increased number of ASRS reports for STARs were (a) more path segments (i.e., waypoints) and (b) more altitude constraints. For SIDs, an increased number of ASRS reports was associated with IFPs that had more flight paths (i.e., transitions). The IAPs analyzed in Chandra et al. (2012) were selected by subject matter experts, not for known operational issues, but for perceived issues. The group of IAPs selected by experts had more flight paths, more path segments, and more radius-to-fix path segments than a baseline group.

We also realize that IFP design can negatively impact visual complexity of the chart because the IFP design affects how many flight paths and other elements (e.g., notes) need to be shown. In Chandra and Grayhem (2013a and 2013b) we established empirically that pilots need more time to find specific information when the chart is visually complex, with many transitions on SIDs and feeders on IAPs. Although pilots may feel that they ignore irrelevant flight paths when searching for specific chart data, our results show otherwise. The time to search for an item on the chart was affected by all the flight paths shown.

A more recent study was conducted in parallel with the current study (Phillips, Yenson, and Olson, 2016). Phillips et al. surveyed 50 pilots to understand their information needs for arrivals and departures. The goal of the study was to determine whether a specific set of briefing information would be useful to pilots for SIDs and STARs. However, their data show that pilots do not think setting aside briefing information for SIDs and STARs would be especially useful. The respondents were more interested in seeing improvements to other chart formatting issues, such as the need to highlight flight path constraints.

1.3 Overview of Study

Having explored objective measures of IFP design complexity and visual complexity of charts, we now turn our focus to subjective complexity of IFPs. Because charts depict the IFP design, we needed to investigate both IFP and chart complexity, together in context, and separately in order to understand subjective complexity fully.

This study focused on the flight crew perspective. Specifically, the goal of this study was to develop a comprehensive understanding of aspects of IFP design and depiction that are associated with subjective complexity for professional line pilots who fly these IFPs regularly. We wanted to understand how line pilots review and use the IFPs, and in particular, we wanted to know what makes an IFP difficult for them. Our goal was to develop this understanding to improve the design of future IFPs.

We used a structured-interview method to gather data from a variety of operators, including major airlines, a regional airline, an air taxi operator, and corporate operators. Pilot participants reviewed and discussed IFPs that we showed them on charts in small groups. RNAV and RNP IFPs were the focus of the study, but one conventional (ground-based) navigation IFP was included for comparison. We showed two SIDs, two STARs, and two IAPs. The discussions covered a broad range of topics.

Our primary goal was to provide data and recommendations to the FAA on the following IFP design issues:

1) What pilot perspectives should designers keep in mind as they develop new IFPs?
2) What factors do pilots feel add complexity to the IFP?
3) What confuses pilots about IFP designs?
4) What IFP design factors create workload for the pilot and how do pilots deal with them?
5) Are there issues for which pilot training could help to mitigate challenges of new IFP designs?

A secondary, but still important, goal of the study was to provide insights on how charts are used in the context of aircraft with modern flight deck FMSs, which were not common when the earlier charting research was completed many years ago (e.g., Blomberg, Bishop, and Hamilton, 1995). We were particularly interested in how pilots used SID and STAR charts. We addressed the following topics:

1) What types of information do pilots focus on during their briefing and discussions with other crewmembers?
2) How do briefings vary, by operator, type of pilot, and type of IFP?
3) When do pilots prefer to refer to a chart versus flight deck systems?
4) Can we identify different chart review strategies?

1.4 How to Read this Report

For those who are interested in an overview of the study and its key findings, we recommend they first read the Executive Summary above, or Chandra and Markunas (2016), which is a 10-page conference paper. The conference paper contains selected examples from our results, and it includes a description of our subjective complexity framework and recommendations.

This longer technical report is the definitive reference for information about this study. It includes supplementary materials not provided in earlier briefings and reports both in the main document and in the appendices.

Section 2 provides a basic introduction to charts and IFPs for those who are unfamiliar with how they are designed. Appendix A presents additional information on the source data for IFP content. Material in Appendix A will be familiar to chart producers, IFP designers, and FAA staff involved in IFP design and development, but may be unfamiliar to pilots and others.

The process of developing IFPs is described at a high level in a separate report (Chandra et al., 2012). FAA Joint Order 7100.41A (2016) describes this process in more detail, explaining the current roles and responsibilities of the many individuals and teams who are involved. Joint Order 7100.41A incorporates the process improvements that were being considered when Chandra et al. (2012) was published.

Section 3 contains a detailed description of the how the study was conducted and how the data were processed and analyzed. Appendices B through E, called out in Section 3, provide all supporting materials (e.g., chart images and participant instructions). Readers may need to refer to the appendices, especially Appendix B with the chart images and questions shown to participants, as they review the rest of the report.

Section 4 presents our extensive formal results, with specific examples of every issue we identified. The results section has five main subsections, which cover:

- How participants do their IFP briefings and reviews, including what chart data they use and when they use it (**Section 4.1**)
- Participant feedback on IFP and chart difficulties (**Section 4.2**)
- Specific examples of IFP and chart difficulties (**Section 4.3**)
- Interactions with Air Traffic Control (**Section 4.4**)
- Flight crew factors, such as their knowledge and use of terms, feedback on their training, and good practices used by our participants (**Section 4.5**)

The findings in Section 4 will be familiar to professional pilots, but may be unfamiliar to others.

Section 5 has our interpretations and insights about the findings of this study. This is where we explain the subjective complexity framework that ties together all of our findings about the different design factors that affect pilot tasks. We also present our observations about how participants used charts, and propose areas for further research.

In **Section 6**, we present recommendations for IFP and chart design that are based on the results of this study. Many of these come directly out of the subjective complexity framework, though some are at a higher level. The recommendations are summarized in the Executive Summary above. They are also in Chandra and Markunas (2016), with additional supporting background information. Section 6 of this report is similar to the conference paper version, but with a few additional details. The material in Appendix F complements Section 6 by documenting how our recommendations fit with past government and industry discussions at the Aeronautical Charting Forum (ACF).

Finally, **Section 7** contains a brief summary of key contributions from this study and reference documents are listed in **Section 8**.

2 Background on IFPs and Charts

Here we first explain in more detail the relationship between IFPs and aeronautical charts (Section 2.1). Next we provide additional background on chart design (Section 2.2). Finally, we offer some insights into IFP and chart complexity from the perspective of an IFP designer (Section 2.3). While this information may be generally familiar to flight crews, it is presented more formally here in order to help us interpret and delve into the details of the data that we obtained in this study. Further information on the source data for IFPs is provided in Appendix A. As mentioned earlier, the steps for developing IFPs, plus individual and team roles and responsibilities, are detailed in FAA Joint Order 7100.41A (2016).

2.1 IFPs Versus Charts

We refer to both *IFPs* and *charts* in this document. We adopted a similar definition as in Advisory Circular (AC) 211-2 (FAA, 1967). An IFP refers to the information and requirements set by the FAA. These are the instructions that specify the route to be flown, laterally and vertically, including any speed constraints. A chart is the depiction of the IFP. More specifically, the chart is a document created to meet the requirement of air navigation. It provides a graphic representation of a specific published IFP that is used to aid pilots in navigation. In other words, a chart is specifically intended to communicate the IFP instructions in a manner that aids pilot comprehension of the route.

Published depictions of airport terminal IFPs (i.e., charts for SIDs, STARs, and IAPs) are released in a static, pre-composed format (paper or electronic Portable Document Format) for all public IFPs, including new PBN IFPs. Currently, airport terminal aeronautical charts are only provided in static format, but in the future, there may be electronic data-driven aeronautical charts, whose format could be constructed and customized in real-time. Data-driven charts are already in use for enroute operations (Larson, 2011). Electronic data-driven aeronautical charts could replicate the format of static charts, or they might present chart data in new ways that are not possible with the static format.

Aeronautical charts provide the pilot with all information necessary to fly the IFP under all allowable conditions. Published charts show the path that the aircraft is expected to fly including transition paths (i.e., branches in the route) that could be flown if so directed by ATC. Charts can be used to verify that the aircraft is following the correct route and complying with required turns, altitudes, and speeds.

2.2 Chart Design

There are different companies that produce charts, such as Jeppesen, NAVBLUE, and Lufthansa Systems/Lido. Individual countries also produce their own charts, such as the FAA charts in the United States. A chart producer converts the IFP specification from the designer into a graphical depiction, the chart. The chart shows all the elements of the IFP that are pertinent to the pilot in a comprehensible format. They describe the IFP and any limits associated with its operational use.

IFP designers also use charts, but in a different way from pilots; IFP designers use charts to document and check the IFP specifications. Prototype charts help to verify that the IFP is designed as intended and that all necessary information is defined properly and available to the pilot. Some of the data that IFP designers use may not be useful to pilots. For example, pilots do not need to know when the parameters for terrain clearance change along the route.

Controllers and dispatchers at commercial airlines also use charts, but they focus on different information than pilots. For example, a dispatcher may be responsible for verifying climb performance to meet the IFP requirements. Controllers may use charts to understand the traffic flow.

Different chart producers may use different graphic conventions to depict the IFP, and a given chart producer may change their own graphic conventions over time. In fact, Jeppesen announced a significant update to the format of their SID and STAR charts in late 2016. These changes will be phased in over the next several months, one airport at a time. Our study was conducted on charts drawn in 2014, so they followed the older drawing conventions, which are described here.

In Section 2.2.1 we describe the information shown on a chart (i.e., its content). In Section 2.2.2 we describe how this information is arranged on static Jeppesen charts, such as those used in the current study; this is the layout of the chart. Finally, Section 2.2.3 considers the visual complexity of charts and how that could be mitigated.

2.2.1 Chart Content

IFPs are, by definition, developed before charts, so there is a hierarchical relationship between the two. All the information in the IFP design is on the chart. For example, notes that specify IFP limitations must appear on the chart. The number of waypoints and constraints in the IFP will be reflected in the graphical depiction. Ambiguities that exist in the IFP design will also appear in the chart.

Most of the information on the chart is necessary for the IFP depiction, but all chart producers add some information that goes beyond the minimum IFP definition. For example, all charts include communication frequencies and IAPs show shaded terrain contours. In addition to operational information about the route, IAP charts contain reference and planning information, such as the minimum weather conditions under which the IFP can be completed, essential equipment requirements, and other constraints for flying that IFP. Some of the additional information is used to support pilot decisions, such as whether or not to fly the IFP and up to what point. This kind of planning information is not available in the navigation database, which has only the route specification. Chart producers also occasionally add their own (nonstandard) notes to the chart when they consider it helpful to the pilot.

2.2.2 Chart Layout

Chart producers use their own internal charting conventions to draw charts. For example, the FAA uses the Interagency Air Cartographic Committee (IACC) Specifications (available on the FAA website). Across different chart producers, there are some general, but not specific, common conventions for chart layout. These conventions produce similar formats and content across different chart producers.

Differences between chart producers can arise because they have different audiences. For example, Jeppesen designs charts for international use and has an international database of airports, whereas FAA only produces charts for airports in the United States, which are primarily used by domestic pilots. Other chart producers might customize their products for airline pilots who fly to major airports in faster aircraft, or for general aviation pilots who fly single-engine airplanes to smaller airports. The chart producer adds value to their chart product by customizing it for their pilot audience.

The design of approach charts was significantly updated about 20 years ago, after a series of research efforts and papers (see for example, Blomberg, Bishop, and Hamilton, 1995; Clay, 1993; Osborne, Huntley, Turner, and Donovan, 1995; Ricks, Jonsson, and Barry, 1996; Wright and Barlow, 1995). However, there has not been a parallel level of research on the design of SIDs and STARs. SIDs and STARs are designed to convey commonly used ATC clearances, but IAPs convey flight paths that avoid terrain, so their design constraints and operational uses are quite different (see Chandra et al., 2012, pp. 23-25).

A chart is divided into sections and is usually arranged on a single image. In the United States, charts are created from FAA Order 8260.19 forms (see Appendix A for examples). Here we focus on the Jeppesen chart format (from 2014), since we used these in the study. The charts we showed to participants are provided in Appendix B for reference.

All Jeppesen SIDs, STARs, and IAPs show:

a) Heading information to identify the procedure
b) Communication frequencies
c) Briefing information
d) A graphic (plan view) of the lateral path

IAPs also have:

a) A description of the missed approach procedure (in text and icons)
b) A profile view of the vertical path
c) Landing minimums in a table

SIDs and STARs also have text instructions for the initial climb on SIDs and landing notes on STARs. Conversion data (e.g., climb gradient tables) are provided as needed.

Briefing information includes IFP limitations and requirements (e.g., “Turbojets only” or a requirement to use the Global Positioning System, GPS). It also includes text about prohibited airspace in the area. On SIDs and STARs, the briefing information also includes the airport(s) that the IFP serves, the elevation of the primary airport, and transition altitude. Briefing information is more detailed on IAPs than on SIDs and STARs; it includes, for example, the final approach course, altitude at the final approach fix, and the decision altitude.

The graphic views on SIDs/STARs and IAPs are similar, but do vary. The graphic shows waypoints along the lateral flight path, course between the waypoints, speed and altitude constraints, and holding patterns. Other pertinent route data are also shown, such as RNP values and minimum altitudes along the route such as the Minimum Obstruction Clearance Altitude (MOCA) or Minimum Enroute Altitude (MEA), and VOR radials. Route-related notes are also shown on the plan view, with specific information (e.g., holding pattern speeds) or references to other information (which may be on a different page). The IAP plan view is drawn to-scale while SIDs and STARs are not. On SIDs and STARs, both Jeppesen and the FAA provide distances between the waypoints along the path. Jeppesen also provides nonstandard notes with direct distances (as the "crow flies") between the termination point for STARs and the runway (and similarly, Jeppesen provides the distance between the runway to the entry point of a SID), for additional context.

2.2.3 Visually Complex Charts

There are only three options for simplifying IFPs that produce visually complex chart designs (discussed in Section 3 of Chandra et al., 2012):

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).

One motivation for developing electronic data-driven charts is that they could potentially do all of the above, in real time, if they are aware of the planned aircraft route. These types of charts could also potentially show information in novel, even customizable depictions to address visual complexity in ways that are not possible with static charts. For example, only relevant notes could be depicted, and those could be grouped and placed in a field that the pilot calls up only when needed.

2.3 IFP Complexity

An IFP designer's view of complexity is shown in Table 1. This table was constructed through discussions with the FAA and industry. The first three rows (vertical, lateral, and speed complexity) are often considered by teams that develop IFPs. They represent an analytical breakdown of the different parameters that can be altered as an IFP is designed.

The last row in Table 1 is a catchall list of other reasons why flying an IFP might be difficult. These issues include the visual depiction, interactions with the aircraft performance or equipment, and interactions with pilot understanding, knowledge, and training. Complexity of the visual depiction can be an unintended byproduct of the IFP design. Sometimes designers do not anticipate a complex visual depiction because they are not aware of chart design constraints.

We will use findings from the current study to update this model of IFP and chart complexity to incorporate line pilot perspectives.

Category	Description and Examples
Lateral Complexity	• Headings/turns and their constraints are unclear or difficult to meet. • Several turns in close proximity, perhaps due to terrain or airspace constraints. • Radius-to-fix (RF) legs.
Vertical Complexity	• Altitudes and their constraints are unclear or difficult to meet.
Speed Complexity	• Speeds and their constraints are unclear or difficult to meet.
Other factors in ability to fly the IFP correctly	• Visual Depiction of the IFP (the chart). The chart may be unclear or ambiguous. Or, the chart may show many elements, where some are not relevant to the planned route. Data elements could be misinterpreted. Elements of the chart may not be compatible with flight deck systems (e.g., in terms of terminology, symbology, or concepts). • Flyability. It may be difficult to meet all IFP constraints in some aircraft types. There may be a constant need for the pilot to monitor flight deck systems, increasing workload. Pilot interventions may be needed. • Clarity. IFP instructions are unclear or ambiguous. • FMS Issues. IFP is difficult to use within some FMSs due to either FMS limits or IFP design factors that interact with FMS design (e.g., route discontinuities, dropping waypoints unintentionally, data exceed FMS memory).

Table 1. IFP designer view of complexity.

3 Method

In this section we describe the study method in detail. First we describe the participants (Section 3.1). Next we describe the study procedure, describing what happened in each session (Section 3.2) from the participant's perspective. The charts and IFPs we tested are described in Section 3.3. The participants' tasks are described in Section 3.4, which includes a discussion of the task fidelity. Finally, in Section 3.5, we discuss the limitations of the study method and the scope of the study.

3.1 Participants

We reached participants through a variety of methods, including advertisements in crew lounges, information sent to them from a coordinator within the operator, or information posted on an internal company website. All participants were based in the United States (US).

All participants were certificated and current professional instrument-rated pilots. Most of them flew domestic operations in the United States, but some had experience flying in Europe. Participants were not required to be qualified for RNP operations. Two participants in the study were on medical leave unrelated to the tasks in the study, but they were each teamed with active pilots. Pilots received a $200 gift certificate for their participation in a single 3-hour group session if allowed by their employer.

Forty-five pilots participated across 19 data-collection sessions between mid-May and mid-December 2014. The participants came from three major airlines, three corporate operators, one regional airline and one air taxi operator. Twenty-three participants were qualified for RNP Authorization Required (AR) operations; this includes all of the major airline pilots and one group of corporate pilots. None of the regional or air taxi participants were qualified for RNAV RNP (AR). Within an interview group, the participants all came from the same operator and flew the same type aircraft, with one minor exception. Just twice, we paired participants who worked for the same operator and flew similar aircraft models (from the same aircraft manufacturer) for scheduling convenience.

Participants' flight experience ranged from 3,200 hours to over 22,000 hours. Table 2 shows self-reported participant flight experience by type of operator. The participants reported their FMS experience in terms of number of years as one of five choices, which were coded as ratings of 1 to 5. A rating of 5 corresponded to more than 15 years of FMS experience, 4 corresponded to 10 to 15 years, 3 corresponded to 5 to 10 years, 2 to 1 to 5 years, and 1 to less than one year of experience. Just two of the 45 participants (one corporate and one regional) reported less than 5 years of FMS experience.

Participants reported that they were comfortable with the FMS and familiar with Jeppesen charts; the average rating for both items was above 9 on a 10-point scale. For the FMS comfort scale, a 10 was described as "Very Comfortable (Other pilots ask me for advice)," 5 was "Reasonably Comfortable," and 1 was "Somewhat uncomfortable (Still new to it)." For the Jeppesen chart familiarity question, a 10 was described as "high familiarity," 5 was "Some familiarity," and 1 was "No familiarity."

Participants also reported high levels of comfort with RNAV IFPs, an average of 6.5 out of a maximum of 7 for both SIDs and STARs. Participants who were RNP AR qualified reported high levels of comfort with these IFPs on the background forms (an average of 6.4 out of 7), though it was clear that their line experience with RNP AR IFPs varied quite a bit through the course of the interviews. All of the participants flew with Jeppesen charts and used these for the study (see Section 3.3).

The participants flew a variety of aircraft types. Some of them flew more than one type aircraft, or referred to past experience with different aircraft types. Table 3 lists the aircraft that participants flew in terms of whether their particular versions had "coupled vertical navigation (VNAV)" (i.e., VNAV coupled to the autopilot) and autothrottle. We do not identify any of the specific aircraft models, manufacturers, or operators in order to maintain confidentiality. The aircraft flown for major airlines seated approximately 100 to 200 passengers, the regional aircraft seated approximately 50 passengers, and the corporate and air taxi aircraft accommodated approximately 10 passengers.

Some of the participants flew with electronic charts viewed on an Electronic Flight Bag (EFB). One corporate operator and the air taxi operator mentioned they were flying paperless operations domestically. Other operators had EFBs for viewing charts, but did not explicitly mention that they were paperless. Different operators had different policies on the use of the EFB for viewing charts. For example, the air taxi operator only allowed one EFB to be used below 18,000 ft. In some aircraft models with advanced avionics, pilots could configure the static electronic charts to appear on large primary flight deck displays if desired.

	# of Pilots	Min Flight Hours	Max Flight Hours	Average Flight Hours	Median Flight Hours	Average FMS Experience (1 to 5)	Average FMS Comfort (1 to 10)	Average Jeppesen Chart Familiarity (1 to 10)
Airline	20	4,500	22,000	12,151	11,500	4.0	9.6	9.7
Corporate	12	7,000	20,000	13,150	13,000	4.6	8.8	9.0
Regional	6	3,300	10,200	6,383	6,000	3.0	9.0	9.0
Air Taxi	7	3,200	20,000	9,853	9,306	4.4	9.1	9.1
All	**45**	**3,200**	**22,000**	**11,291**	**11,000**	**4.1**	**9.2**	**9.3**

Table 2. Participant experience.

Aircraft Manufacturer	Aircraft Model	Type of Operation	VNAV Type	Auto-throttle?
A	1*	Major Airline	Coupled	Yes
	2	Major Airline	Coupled	Yes
	3	Major Airline	Coupled	No
B	1	Major Airline	Coupled	Yes
C	1	Regional	Advisory (for Descent only)	No
	2	Major Airline	Coupled	Yes
D	1	Corporate	Coupled	Yes
	2	Air Taxi	Coupled	No
E	1	Corporate	Coupled	Yes
	2	Corporate	Coupled	Yes
	3†	Corporate	Coupled available, but used in Advisory mode	No
	4	Regional	Advisory	No
F	1	Air Taxi	Coupled	No

Table 3. Aircraft and automated systems flown by participants.

*Two different operators. All other models were with just one operator.
†Coupled VNAV can be "coupled" to the autopilot at pilot discretion. Can configure it to only give advice.

Appendix C (Participant and Group Highlights) describes the participants and groups in further detail. The table lists the number of participants in each group. Each group had either two or three pilots, with one exception. When there was a last minute cancellation, we interviewed a single pilot. We did not require Captains and First Officers to be in the pair. However, across the entire participant group, there were approximately equal numbers of Captains and First Officers.

3.2 Study Procedure

Some of the interviews were held at airports where the participants were based, some were held at a training center, and some were held at the Volpe Center. Each interview took place in a conference room, with minimal interruptions.

Each session ran for approximately three hours. Two researchers were present, with laptops for taking notes. We did not record audio or video of the interviews, but independently took detailed notes, transcribing much of the conversation nearly verbatim in real time.

Figure 1 illustrates the flow of the study from the participants' point of view. We first introduced participants to the plan for the study and their task. They signed an informed consent form that described the study, the foreseeable risks, and the rights and responsibilities of the participants, including noting that participation in the study was voluntary and confidential. Next, participants filled out background information about their flight experience (shown in Table 2) before they began the IFP review task, which is described in Section 3.4.

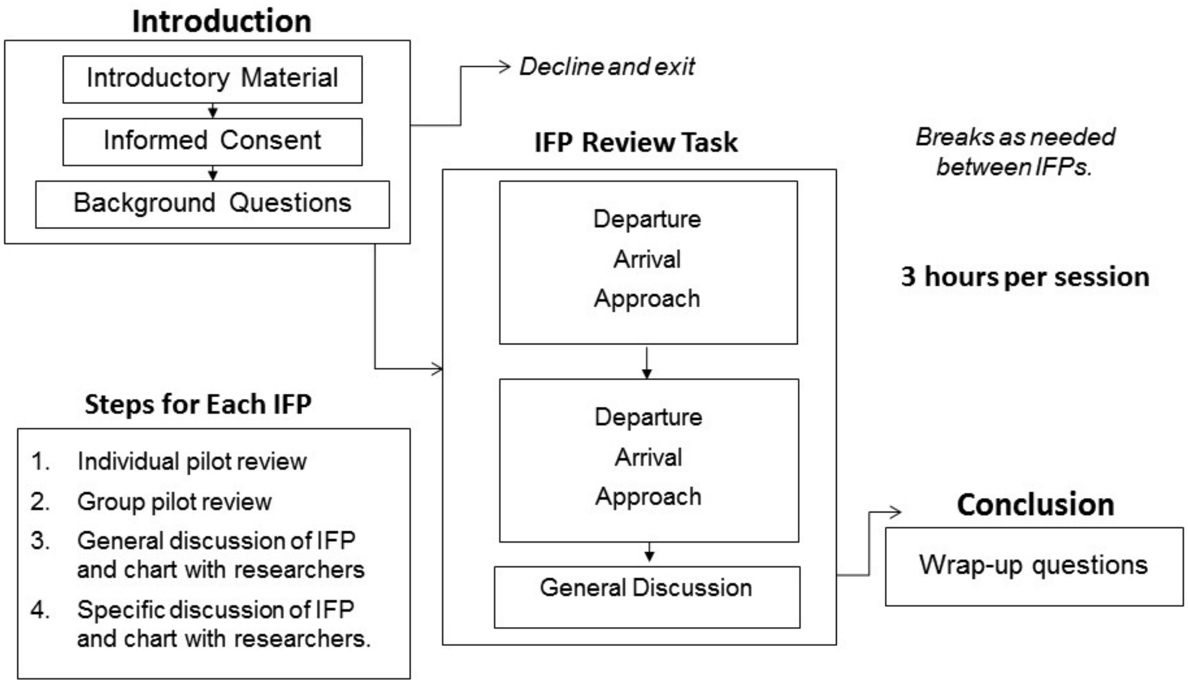


Figure 1. Flow diagram of the study.

The introductory and concluding materials are provided in Appendix D. These include an introduction that we read to the participants, a script with instructions for the individual review and group review, and a list of questions for discussion after all the IFP reviews were finished. After completing all the IFP reviews, we concluded the session with a discussion of IFP and chart complexity in general, asking:

- What features make an IFP difficult?
- What features make a chart difficult to use?
- Do you have any pilot training recommendations for the IFPs we reviewed?
- What would you like designers to know about your use of these IFPs and charts?

Participants also had a chance to provide general concluding comments and to ask the researchers about the project.

3.3 Stimuli

Participants reviewed six IFPs. We divided these into two sets shown in Table 4. The first set lists four charts, but participants saw only one of the two Boise approach charts. If they were qualified for it, they saw the RNAV (RNP) Z approach otherwise they saw the RNAV (GPS) Y approach.

The order of the sets was counterbalanced across sessions to reduce potential effects of fatigue over the course of the session. The charts are provided in Appendix B along with the questions that we asked for each one. Appendix B includes both the FAA and Jeppesen versions of the charts for reference and comparison. Note that the IFPs or charts used in the study may have been updated recently, but the charts in Appendix B were current at the time of data collection. For ease of reading, when referring to data from discussions about an IFP tested in the study, we use a short version of its name (e.g., BLZZR) rather than the full name given in Table 4.

Set	Type	IFP	Description	Airport
1	SID	BLZZR TWO RNAV	RNAV departure with multiple crossing runway transitions and no common route.	Boston, MA (BOS)
	STAR	FRDMM TWO RNAV	RNAV Optimized Profile Descent (OPD) arrival. Multiple window-altitude constraints.	Washington, DC (DCA)
	IAP	BOISE RNAV (GPS) Y 28L	RNAV (GPS), for pilots who are not RNP AR qualified. LPV, LNAV/VNAV, and LNAV options.	Boise, ID (BOI)
		BOISE RNAV (RNP) Z RWY 28L	RNAV (RNP) AR approach with multiple transitions for qualified pilots.	Boise, ID (BOI)
2	SID	EDETH ONE RNAV EDETH TWO RNAV	RNAV departure with short runway transitions, a common route, and three long enroute transitions.	Salt Lake City, UT (SLC)
	STAR	KORRY THREE	Conventional arrival with VOR radials.	New York, NY (LGA)
	IAP	DEN ILS/LOC RWY 35R	RNAV transition to ILS.	Denver, CO (DEN)

Table 4. IFPs reviewed.

We supplied paper copies of the Jeppesen charts for the review and had an iPad with the Jeppesen Mobile FliteDeck software available as well. Participants were also able to call up the charts on their own company EFB if they preferred. In almost every session, participants used the paper charts for the review and briefing, not the EFB, simply for convenience.

We printed the charts on single sheets of 8.5” by 11” paper. Standard Jeppesen charts (“size 1”) are roughly half this size. However, as it happens, Jeppesen uses a nonstandard full page (“size 2”) format for all of the IFPs we used in the study except for the Boise RNAV (GPS) approach. This is because the tested IFPs required the larger format to be depicted clearly. So, the paper charts we printed out for participants were the same size as the actual Jeppesen publications. Standard Jeppesen charts come in a binder, with holes punched down the long side, but ours did not. We also noticed that charts printed from our iPad or on different printers sometimes had different line thicknesses. Because our study focused on the IFP design, differences in the paper copies were not expected to affect the results.

In order to maintain consistency with the electronic chart versions, we always used charts that were current at the time of the session. The result was that some IFPs changed over the course of the data collection. For example, EDETH ONE changed to EDETH TWO. The Boise RNAV (RNP) Z approach also changed mid-way through the study, but none of our later participants used the newer version because they were not qualified for the RNP IFP.

3.4 Task

First we describe the tasks that participants did in the study (Section 3.4.1). Next we describe how these tasks would be done in actual operations by presenting industry advice for reviewing and briefing IFPs

(Section 3.4.2). In Section 3.4.3, we compare how these tasks are done in actual operations with how they are completed in the study as part of a discussion on the overall fidelity of the study.

3.4.1 Description of Tasks in Study

The review of each IFP consisted of four steps:

1) Individual review
2) Group review (briefing)
3) General discussion of IFP and chart
4) Specific discussion of IFP and chart

The first two steps represent tasks that pilots do in the flight deck while preparing to fly an IFP. Therefore, we observed the participants during the first two steps without interruption. We allowed the participants as much time as they wanted for both the individual and group reviews, asking them to do what they would "normally do." The individual reviews were done in silence. When there were two participants in the group, they alternated briefings, so they each led three of the briefings. When there were three participants in the group, each one led the briefing for two IFPs during the session.

All questions and discussion were reserved for the last two steps. When talking with participants, we used the casual term "procedure" to refer to an IFP. First, we asked the pilots general questions about their briefing. Specifically, we asked:

- What elements did you brief and why?
- What challenges might you anticipate in flying this procedure? In general? For the aircraft type you normally fly?
- What (if anything) struck you as unusual about this procedure?
- What (if anything) struck you as unusual about this chart?
- How would you describe this procedure to another pilot?

Finally, we asked the participants specific questions about the IFP they reviewed. These questions were different for each of the six IFPs; they are provided Appendix B.

For the discussion, we emphasized in the instructions (Appendix D) that participants should "consider all types of complexity and potential for confusion" so that we could inform designers about any potential for confusion in the IFP design. We also told participants that we wanted to understand how charts are used in normal operations in the context of modern flight deck systems so that we could identify areas for improvement in charts and IFPs.

The discussion questions focused on the flight path planning task, but, in response, participants also provided supplementary information such as a description of their flight deck systems, capabilities, and displays, plus a description of relevant company operating procedures and policies. Sometimes we also looked up IFPs that the participants brought to our attention, which they thought had issues related to the IFP under review. We allowed this supplementary discussion as much as possible, keeping the schedule in mind. If there was available time, we showed the participants the FAA chart for the IFP to get their reaction to its design.

3.4.2 Description of Tasks in Actual Operations

Lutat and Swah (2013, p. 64) recommend a "three-step glass cockpit briefing" to pilots of aircraft with FMSs. These steps are:

1) "Build," load, or select the appropriate procedure from the FMS database with direct reference to the current chart.
2) Rigorously check the FMS programming for compatibility with the aircraft clearance.
3) The pilot flying (workload permitting) briefs the procedure from the FMS, while pilot monitoring (ideally) checks the programming against the appropriate chart(s).

Checking the route in the FMS against the chart is important because the static chart is the legal authority, but the route in the FMS is critical because that is the path the aircraft will fly.

Forrest (2015) also provides practical guidance to pilots about how to conduct briefings. He emphasizes the need to do the briefing in the first place, and then to be careful to select the most important few points to cover. Even when the briefing is routine, pilots should go over a few key points to avoid complacency. He points out that an effective briefing can be done within a minute or two, and the time is well spent even if just to reaffirm understanding. Interestingly, he mentions that volume, cadence, and style are "significant, but often overlooked, components of a briefing."

Veillette (2016) discusses preparation for arrival and approaches in terms of energy management. He says that late approach preparation and briefings can result in rushing, and crews may omit important steps, which could lead to unstable approaches and landings. He recommends completing the approach briefing 10 minutes before the top-of-descent.

3.4.3 Fidelity

There were two important aspects of the study that increased its fidelity. First, the participants within each group flew for the same operator and flew either the exact same aircraft type, or a similar model. This meant that participants were familiar with the same standard operating practices at their company and could discuss technical details about their aircraft systems. Second, participants used Jeppesen charts in the study. This was critical because of the high level of familiarity participants had with that chart format.

There were some unrealistic aspects of the study, which we attempted to mitigate. First, participants could not access flight deck systems. As mentioned by Lutat and Swah (2013), flight crews would normally use these systems during their IFP reviews and briefings. During the individual review, participants had to develop a mental representation of the IFP using the chart alone. Pilots who rely upon the flight deck systems to help them review the IFP might be less comfortable completing the task with only the chart in front of them. To compensate for this lack of a familiar environment, participants explained to us what systems they would use, when, and why. These explanations helped them to build a context around the situation, which seemed to make them more comfortable with the task in the study.

Also, during a normal briefing, Lutat and Swah recommend that pilots compare data between the chart and the FMS. One pilot reads out the necessary information from the FMS display to the other pilot who is looking at the chart to make sure the FMS route matches the charted one. In the study, both pilots looked at a chart since there was no FMS navigation display. So, in the study, the purpose of the briefing was to ensure a common understanding between the two pilots, not to verify the FMS route (since there was no FMS available).

Another unrealistic aspect of the study was that we did not give participants a clearance or a weather scenario, which they would normally have. Instead, they decided what route to brief and could choose to review more than one route if desired. They could also assume different types of weather conditions.

We wanted to observe what they chose to do. We were open to having them discuss what they would do under different clearance and weather scenarios.

Overall, we were able to strike a reasonable balance in the formality of the briefings and reviews in this study. Having two or three participants in the session from the same operator increased the formality of the briefings relative to having a single participant in the room. Because we were not experts in flight operations, participants were more relaxed with us as observers than they would have been with, for example, a management pilot or FAA inspector as the observer. Participant briefings and discussions indicated that they reviewed the IFPs at a realistic, but not unusually detailed, level. Participants who had questions about the IFP or chart appeared comfortable discussing those issues with researchers. The pace of the individual reviews and group briefings also seemed realistic. Participants did not appear especially rushed or especially slow in their reviews and briefings.

3.5 Method Limitations and Study Scope

The interview method had limitations, some of which were discussed earlier (Section 3.4.3). In particular, we did not observe participants flying the IFPs. We only talked about how participants would fly them. So, we do not have data on actual flight performance. Because we were in a conference room, participants could not access an aircraft simulator or a mockup of flight deck displays, although sometimes we were able to open a view of their flight deck in a paper diagram or an online picture for reference. Some participants missed these systems more than others for the chart briefing, but all were able to complete the study.

There were additional limitations of the study methodology. For example, the results are derived from the group opinion of the participants in each session. We were not usually able to separate out individual participant data, opinions, or experience. This reflects reality; the aircraft types in our sample require two crewmembers, and these two reinforce or fill any gaps in each other's knowledge.

The discussion was structured, but sometimes led in directions that we were not able to explore fully due to time limits, or due to gaps in communication between the participants and researchers. It was sometimes difficult for participants to explain details, for example, about what their flight deck display might show under a particular set of circumstances. The result is that there are some topics for which we might not have enough information to determine what the root problem was.

The study was also limited in terms of the data that we collected. Although the data were from a broad sample of participants who flew a range of aircraft types, the sample is not deep, meaning that we cannot always drill down to look at questions within a type of aircraft of a type of operation. We would need to collect additional data if there are questions that focus on a subset of our participants. Also, none of our participants regularly flew light general aviation (GA), single-engine operations. Our focus was on commercial operations and pilots who have significant experience, at least with RNAV procedures if not RNAV (RNP). Additional data could be gathered about chart use from light GA pilots for a more complete understanding. For example, light GA pilots may be more interested in certain types of chart notes or takeoff obstacles near the runway.

Finally, the scope of the study was limited. The observations and feedback we received were focused on the IFP design and the chart; additional work could be done to understand the role of the FMS and other aircraft automated systems, ATC clearances, or pilot training, in understanding and flying the IFP. Also, we did not compare how IFP briefings varied based on whether pilots briefed from an EFB versus the paper chart. That could be a separate study to see if briefings change based on the media on which pilots view the chart. Finally, we did not systematically examine operator policies regarding IFP reviews and briefings.

3.6 Data and Analysis

We collected notes from the discussions. The raw notes were transcripts of the sessions generated in real-time. There were two sets of notes for each session, one from each researcher. We did not gather performance data. For example, we did not record the time spent reviewing each chart or the accuracy of the briefing. We also did not record any interactions with the flight deck systems because those were not available to the participants in the study. No statistical analyses were performed.

We rearranged the raw notes into a standardized summary file based on the template and rubric provided in Appendix E. The template is organized by topic, so it is easier to compare data for different topics across the summary data files for each session. We created the rubric based on a subset of data from the early sessions to understand what topics were important. Because the discussions in each session varied, not all topics were covered in every session.

In order to create the final summary file for each session, we completed the following steps:

1. Created first draft summary file from one researcher's notes. Condensed and rearranged information so that it fit under the correct topic area in the template.
2. Reviewed the first draft summary file against notes from the second researcher. Reconciled any discrepancies or questions. Added or amended information to clarify gaps or questions as needed.
3. Inserted annotations and cross-references in the summary file. For example, we reviewed any related IFPs suggested by the participants and added notes to the summary file about these. Inserted researcher insights and observations about the data, as well as questions for follow-up.
4. Both researchers jointly reviewed the draft summary to resolve open items.
5. Iterated to check that all information was under the correct topic heading. Sometimes the information was duplicated under related headings and cross-referenced within the file.

Creating the summary files was difficult because topics were often subtly related and sometimes overlapped with each other. For example, the section on "VNAV Operations" had data about how participants *chose* to use their VNAV system. If the VNAV system had specific characteristics as to how it worked in the airplane, we placed those under the "Equipment" section, because it was a description of their airplane system.

When complete, the summary files were much easier to read than the raw notes and they were more concise as well, just 8 to 10 page long. We used them to perform analyses on specific topics using the following general process:

- Identify sections of the summary files with relevant information.
- Aggregate data across session summaries, from different sections as needed.
- Categorize and organize the data specific to that topic in a new file.

4 Results

As mentioned in Section 3.6, our data consisted of summary files for each session, which were based on notes taken independently by two researchers. The notes taken by the two researchers were highly related, which indicates that most of the session was recorded. Having both note-takers miss recording the same portion of the interview was unlikely. So we have high confidence in the quality of our data, within the limitations discussed in Section 3.4.3 and 3.5, of course.

We obtained two types of results. First, there were our observations about how participants completed their individual reviews and briefings. Second, we had participant responses to our discussion questions.

In many cases, participant responses were far ranging and covered more subject matter than was directly requested in the question. For example, participants often mentioned IFPs that we should look at other than those in the study, which we did. They also talked about typical operational use if they were familiar with the local airspace or the specific IFP we discussed.

Where appropriate, we further analyzed participant responses in order to categorize and understand them. However, in this section, we focus on what we directly observed or heard from participants. Our interpretation and a discussion of the findings are in Section 5.

Here, we first discuss how participants completed their individual reviews and group briefings (Section 4.1). Next we present participant feedback on factors they believed created difficulty in flying IFPs or using charts (Section 4.2). These issues were categorized as being related to the IFP or to the chart, or both. If the chart manufacturer could independently resolve the issue by adjusting the graphics, that was considered to be a chart-specific issue. Anything that required a change to the IFP design or content that the chart producer obtained from the IFP designers was determined to be induced by the IFP design. Section 4.3 contains several examples of IFP and chart issues that we discovered. After detailing the chart and IFP issues, we present participant feedback about interventions by ATC (Section 4.4). Finally, we discuss our results related to crew factors, such as their knowledge of specific terms, their reflections on training, and good practices that we observed (Section 4.5).

The results presented here are all based on the Jeppesen charts used in this study. We do not present any findings specifically related to the FAA chart design. Although some groups had time to look at the FAA charts, they frequently commented that these charts were hard for them to interpret because of their lack of familiarity with the chart format and drawing conventions.

4.1 IFP Reviews and Briefings

IFP reviews and briefings help pilots to become familiar with what they need to know to fly the IFP correctly. Our participants anticipated potential areas of confusion during the review and addressed these in the briefing. They used charts for both reviews and briefings, but in different ways. Participants became familiar with chart elements and their arrangement during the individual reviews. Sometimes they identified specific information from the chart in advance so that it would be readily accessible later, when needed in flight.

One of our goals for observing IFP briefings and reviews was to identify the process and techniques that participants used. Once we identified these, we could look for areas of improvement to ensure a thorough understanding of the IFP. Another goal of these observations was to look for improvements in the design of the chart depictions to support good briefings and reviews. By "chart design" we refer to not just the content, but also its arrangement and presentation of data (as discussed in Section 2.2). It is particularly important to understand chart design in the context of today's flight deck, where pilots normally use the navigation display and other flight deck systems during their briefings and reviews along with static charts (as described in Section 3.4.2).

Here, we separate *process* from *content*. The *process* has to do with *how* pilots accomplish the task, *when* they do it, and *who* does it. The *content* has to do with *what* chart elements pilots use to complete the task. By understanding the briefing and review process and content, we should be able to anticipate more accurately how pilots might react to future proposed changes to the design of charts and IFPs. We also expect that this understanding will lead to insights in identifying issues and developing recommendations for the design and use of data-driven terminal charts.

IFP reviews are discussed in Section 4.1.1, briefings are covered in Section 4.1.2, and Section 4.1.3 takes a closer look at how our participants used specific chart data elements.

4.1.1 IFP Reviews

When given an IFP and chart without a clearance, the first thing our participants did was create their own clearance. They reviewed only the flight path for that clearance. That clearly answered our first question as to whether participants would orient themselves to the entire IFP, or just to one path. Only a few participants reviewed the IFP beyond the intended route of flight. They also developed their own weather scenario. Sometimes they discussed more than one weather scenario (e.g., fair weather versus instrument meteorological conditions).

Participants reported that pilots look at charts and flight deck systems, such as the FMS control and display unit (CDU) and navigation display, to complete several tasks during the reviews, including those listed below:

- Check the effective dates of the FMS database and the charts, to ensure they are up to date.
- Correlate and integrate flight path descriptions from multiple sources, reconciling any discrepancies, errors, and discontinuities. The pilot may load the route into the FMS automatically or build the route manually. If it is automatically loaded, the pilot will still check for errors. Sources of information about the route include:
    - Filed route
    - Cleared route (e.g., a pre-departure clearance)
    - Route entered in the FMS and displayed on the navigation display and/or the CDU
    - Route shown on the static (paper or electronic) chart
    - Automated Terminal Information Service (ATIS) or Digital ATIS (D-ATIS) if available (e.g., expected runway)
    - Mental representation
- Review and verify route transitions loaded in the FMS.
- Once the route is loaded and verified, review all waypoints and constraints.
- Review and confirm that aircraft performance can handle the constraints if there is any doubt.
- Review local area information if unfamiliar.
- Confirm the final altitude and departure frequency with the pre-departure clearance (PDC)
- Verify required equipment and capabilities.
- Identify special features or highlights about the IFP that the other pilot may need to know such as important notes, special equipment or capabilities required, dramatic changes in altitude within a short distance, certain types of constraints, and prohibited airspace. These items will be mentioned in the briefing.

During the review, the pilot may be building a mental representation of the route if it is unfamiliar, or he/she may be drawing upon knowledge from a previously built mental representation of the route if it is familiar.

Participants told us that the review could be done by just one pilot or by both pilots separately. There was no firm convention across operators. Often the Pilot Flying (PF) was the one who built the route in the FMS, workload permitting, but sometimes the Pilot Monitoring (PM) built the route. Participants mentioned that it is especially important for the PF to understand the route and to be mentally engaged so that he/she knows what needs to be done.

Crews for one major airline mentioned that their company policy was that pilots must complete "independent reviews" for all IFPs. Each pilot is expected to independently review the chart and the route loaded in the FMS. Other operators may have similar policies, but we did not examine operator policies systematically.

One corporate participant (Group 18) mentioned that if the other pilot built the route, he would have to find another time to get the route “in [his] head.” For departures, that might happen while the crew is taxiing. A different group of corporate participants (Group 1) mentioned that even after the verbal briefing, they would keep reviewing the IFP in detail on their own. Not everyone who acted as PM mentioned this level of diligence to find time to understand the route thoroughly.

Participants used different strategies during their individual IFP reviews. The time spent on individual review of the IFP in the study varied considerably. Some participants just began reading off the chart for the verbal briefing without any visible preparation at all. Others spent a minute or two looking over the chart carefully. However, we also noticed that the time spent on the individual review was only loosely related to the quality of their review. Some participants absorbed the chart information quickly and found what they needed to know in a short time. Other participants who did quick reviews missed information from the chart. For example, one group that did not spend any time on the individual review (Group 4) did not notice the second page of the Boise RNAV (RNP) Z approach chart during their individual review and they did not brief any of the waypoints that were only shown on the second page. In reality, pilots would have to spend some time setting up the IFP in the flight deck systems, and that time may likely be the biggest factor in determining how long they looked at the IFP before the verbal briefing. Setting up the FMS would also force them to look at every waypoint along the route. The group who missed the second page of the Boise RNAV (RNP) Z approach procedure pointed out that they would have noticed the additional waypoints on their FMS.

We observed that some participants did calculations to check climb/descent angles and speeds during their reviews to be sure they could make altitude and speed constraints. When an IFP had transitions, or many waypoints, some participants followed the route with a pen or finger. Another strategy some participants mentioned for ensuring they are on the correct path was to use the navigation display to scroll through the waypoints along the route. Some participants said they used the highlighting feature on the EFB software to highlight constraints during the individual review.

4.1.2 Briefings

We learned a great deal about how participants used the charts to brief an IFP. These results are broken into different topic areas in each of the sections below. Section 4.1.2.1 sets the stage for these results by reminding us what the goals of a briefing are. Section 4.1.2.2 presents what we learned about how pilot briefings are done in practice by a flight crew. Sections 4.1.2.3 and 4.1.2.4 discuss the structure and content of briefings, respectively. Sections 4.1.2.5 and 4.1.2.6 discuss the amount of time spent on the briefing, and when the briefing is done, respectively. In the last section, Section 4.1.2.7, we describe how briefings vary in normal operations.

4.1.2.1 Goals of a Briefing

“To brief,” a transitive verb, is defined as follows in the Merriam-Webster online dictionary (http://www.merriam-webster.com/):

1. To make an abstract or abridgement of
2. a: to give final precise instructions to
   b: to coach thoroughly in advance
   c: to give essential information to
3. To discuss (as a military operation) in a briefing <briefed the mission>

This definition highlights the brevity of the briefing (in referring to an "abstract or abridgement") while also noting its thoroughness and focus on "essential information."

The net action is that one person tells the other person what they *need* to know without extraneous information that would take more time. Briefings should be short, but also they must be precise (providing exactly the correct information) and thorough (providing *all* the necessary information). This implies that the person who leads the briefing is aware of more information than what they convey during the actual briefing. The briefer is *selecting* what information the other person has to know. The listener may only be aware of the information that the briefer brings up, or he/she may have additional context.

4.1.2.2 Briefings in Practice

In practice, one pilot, usually the one who has studied the IFP and chart on his/her own, informs the other pilot about the route, quickly and precisely. Because briefings are fundamentally a *verbal* transfer of information, all the names of waypoints along the route are spoken out loud. The listener may interrupt the briefing if he/she catches an error. After the speaker has finished, the listener can ask for clarification on any point. They discuss areas of potential confusion.

The air taxi operator in our study used what they called a "dual verification" process to brief SIDs. Pilots who programmed the FMS referenced the clearance, charts, and flight plan during the verbal briefing, while the other pilot (who did not build the route in the FMS) read from the FMS to verify the route. This process was also recommended for building and reviewing STARs.

The dual-verification process is similar to the three-step briefing process recommended by Lutat and Swah (2013) (see Section 3.4.2). Other participants in the study said they would use a similar process, where one pilot would read the route off the FMS while the other pilot looked at the chart. Often the PF entered the route into the FMS and led the briefing, but this varied.

4.1.2.3 Briefing Structure

The briefings we observed were structured. Participants had a template for what information they wanted to cover. A generic briefing began with the IFP title and other identifying data (e.g., effective date and page number). Then the participant briefed the route they expected to fly (i.e., the clearance from ATC), including the transition. The participants reviewed the lateral and vertical route, altitude and speed constraints, set up of automated systems, and expectations. It was common to end the briefing with an invitation for the listening pilot to speak up, such as "Any questions?" or "Did I miss anything?" However, we observed considerable variability across briefings, across individual participants, and across types of IFPs. This variability is covered in Section 4.1.2.7.

Some participants mentioned that their operator provided general guidelines about what to brief for approaches in the Flight Operations Manual (FOM). A few participants mentioned that they did not recall any specific guidance for briefings SIDs or STARs.

We did not have access to the FOMs for all the operators who participated in the study, but we had excerpts from two different major airlines. Both of our sample excerpts focused on approach briefings and did not provide guidance on briefings for SIDs and STARs. An exploratory study (Phillips, Yenson, and Olson, 2016) similarly found that, according to a survey of 50 pilots, operators did not consistently provide guidance on how to brief SIDs and STARs. Phillips, et al. did not examine materials from the operators, but asked participants what they recalled. Participants who flew for the same operator did not always agree on what guidance they were given, so their recollections may have been flawed.

4.1.2.4 Briefing Content

We observed, and participants stated, that the content of briefings varies based on factors such as familiarity with the IFP, participant familiarity with each other, and weather conditions. Participants would select different types of information to highlight during the briefings depending on such factors. Section 4.1.3 explains what we observed about the use of chart data in detail.

One corporate group (Group 18) mentioned that they briefed IFPs more than once, focusing on different elements each time. The first briefing would be the most detailed, with successive briefings highlighting just the most critical information they might need in the immediate future. For example, they might first brief the full departure, then just mention the highlights of the departure during the pre-takeoff checklist, then they would go over just the emergency contingencies as they taxied out.

4.1.2.5 Time Spent on Briefing

During the open discussion, participants told us about what they do to prepare for takeoff and landing beyond reviewing and briefing the IFPs. They have to discuss many items in addition to the route, such as the weather, information from the ATIS, special operational procedures they may need to comply with, fuel, runway lengths, and checklists. Participants said they review a lot of information to prepare for a flight and these conversations all take time. The IFP briefing is done in the context of all these other conversations, so participants said they try to minimize the time they spend on it.

We instructed pilots to complete the briefing as they would in normal operations. Although we did not specify how much time participants had to do the briefing, we observed briefings that were quick, reflecting the reality of time-constrained flight operations. Most briefings were completed in just a minute or two, sometimes faster. This is likely close to the amount of time they would spend on briefings in actual operations, though they could be even faster if especially time-constrained. Even with a quick briefing, some participants covered more content (and were more thorough about discussing different aspects of the IFP) than others in the briefings we observed. Some participants mentioned that if they got a late clearance amendment, they might not have time to do a full briefing. (See Section 4.1.2.7 for more on late route amendments.)

Participants told us that the time spent on briefings could be shortened to fit the time available in a constrained situation. For example, there may be significant time pressure to complete the briefing for an on-time departure. Arrival briefings can be a bit more relaxed if they can be done during cruise using D-ATIS to set up the arrival runway and landing.

4.1.2.6 Timing of Briefings

Participants said they prefer to review and brief arrival and approach briefings while in cruise, when there is more time available. However, this can mean that an approach briefing is done a long time before the actual approach is completed, as much as 45 minutes to an hour later. Departure briefings are done “at the gate,” before push back. The departure runway is confirmed in the pre-takeoff checklist. As mentioned in Section 4.1.2.4, Group 18 said they would brief the IFP at different times, focusing on different data.

4.1.2.7 Normal Variations

Even though the briefings were short, the time participants spent on the briefing could still vary considerably depending on many factors. For example, we noticed that corporate participants who flew together consistently on the same exact airplane did very quick briefings, probably because they knew each other and that one airplane so well that a lot of their briefing was standard and therefore not verbalized. (Airline pilots do not have the advantage of flying just one specific aircraft all the time. They fly the same general type of aircraft, but airplanes may differ within the same fleet. For example, the version of the FMS software may vary.) Airline participants did very quick briefings if the airport was familiar (especially if they had flown there recently) and if the weather was good.

If an arrival is amended and a new one has to be briefed while in the middle of arrival, participants said they would abbreviate the briefing because there are a lot of steps and workload associated with updating the route in the FMS. Participants reported that sometimes there is barely enough time to update the FMS, and no time left to re-brief the constraints and highlights of the amended route. Participants pointed out that they sometimes were given more than one amended arrival route, one after the other, which creates a high level of workload.

If they do not have time to recheck the constraints, most participants said they were not satisfied, but since they have to keep flying, they shed the task. Just one participant (Group 6) said that he would reject a late routing change from ATC. Group 18 mentioned that if they were given a late change to their departure runway, they would park the aircraft to review the change. Group 11 mentioned that they would put the aircraft in heading hold mode while they sorted out a clearance amendment in flight.

Some participants said they put away the static chart after the briefing is finished, but others kept the chart available. Reported use of the chart after the briefing varied greatly even between individual participants from the same operator.

4.1.3 Use of Chart Data

Here we look at different elements of the chart to determine whether and when participants used the element. The study was not designed to systematically address this topic, but we are able to gather some interesting findings by observing participants use the charts to brief the IFPs. This information may be useful when developing data-driven terminal charts, which could be customized for different aircraft or operators. Keep in mind, however, that our data are from professional pilots based in the United States who fly RNAV regularly. These data may not reflect the needs of other types of pilots and operators.

Each section below provides details about the use of a different data element. The sections below are ordered roughly from the most-used elements to the least used elements. Table 5 provides a summary of how elements were used. Elements that were not used consistently were sometimes considered to be clutter. Chart clutter, and its different sources, is discussed further in Section 4.3.13.

Usage	Data
Consistently used	• IFP title • Briefing strip for approaches • Graphic callout boxes for constraints • Shaded terrain on approach charts • Minimum Safe Altitude (MSA) on IAP (and often on SID/STAR too) • Text and graphical route representations (both) • ATC communication frequencies on SIDs
Sometimes used	• Climb gradient table • Takeoff obstacles • Notes • ATC communication frequencies on STAR
Rarely used	• Full lateral course • Segment altitudes for obstacle clearance and radio reception on SID transitions • Cross radials for ground-based navigation on KORRY • Waypoint latitude/longitude

Table 5. Use of chart data elements.

4.1.3.1 IFP Title

All groups used the IFP title to begin the briefing, except Group 2 who did not mention it. Participants often also mentioned the effective date and/or chart page number at the start of the verbal briefing. Group 2's briefings were very informal throughout the session, which may explain why they did not state the IFP title.

4.1.3.2 Briefing Strip for Approaches

Approach briefing strips have several fields, some of which vary based on the type of approach. Pilots like and consistently use the approach chart briefing strip to structure their reviews. All of the groups in the study used the briefing strip on approaches. Groups 18 and 19 appeared to use it primarily for individual reviews, not for verbal briefings. Just one participant (in Group 11) said he does not use the approach chart briefing strip. Two of the major airlines in the study (Groups 2, 3, 7, 8, 9, 10) provided pilots with company-specific briefing cards for RNP AR approaches, which supplement the standard approach chart briefing strip. On the Boise RNAV (RNP) Z procedure, Groups 1 and 2 noticed and liked that the briefing strip was duplicated on both pages of the chart.

Participants said they use the approach chart briefing strip to check their FMS entries. However, Group 7 mentioned that they brief off the FMS in the same order as the briefing strip, but they are not looking at the actual briefing strip as they do this task. It is logical to use the same order and go back and forth with the paper, but they primarily used the FMS. So, interestingly, at least one group used the briefing strip as a secondary reference, not the primary reference.

Participants said they would use the approach briefing strip more formally if they were flying in instrument meteorological conditions. Some participants assumed poor weather and demonstrated how they would do a more thorough briefing, while others assumed fair weather and did a simpler briefing.

The Jeppesen Denver ILS chart in the study had a nonstandard two-panel format: the briefing strip is above the RNAV transitions on the left side, but the profile view is at the bottom of the right side under the ILS, diagonally across the page from the briefing strip instead of directly below. Many participants remarked upon this nonstandard layout and awkward flow. If they noticed it during their individual reviews or if they had prior experience with the airport, participants were able to sort out any confusion prior to doing the briefing. However, some participants who were not familiar and may not have examined the chart sufficiently during the individual review did have trouble briefing the IFP (Groups 9, 11, 12, one participant in Group 13). (In addition, Group 6 only briefed the ILS and ignored the RNAV transitions.) The unusual chart layout disrupted their normal briefing pattern.

Jeppesen also shows briefing strips on SID and STAR charts. Participants used these briefing strips inconsistently. There were just four fields in the SID/STAR briefing strips for our test SIDs and STARs: ATC frequency, airport elevation, transition level and altitude (which is always 18,000 ft in the United States), and the notes field. Of these four fields, participants only briefed the notes in the study, and not always consistently (see Section 4.1.3.10 for more about the use of notes).

4.1.3.3 Graphic Callout Boxes for Constraints

All groups used the callout boxes on the graphical view of the route. Participants used the boxes to quickly identify constraints to mention in the verbal briefings. Some participants (e.g., Groups 8 and 13) said they use the highlighting feature on the EFB chart software to highlight constraints as well.

The graphical depiction is the main source of information for speed and altitude constraints. These constraints may also be shown in other places (e.g., in the text route descriptions or in separate notes), but the graphical view is where participants specifically searched for constraints.

4.1.3.4 Shaded Terrain on Approach Charts

All 19 groups said they use the shaded terrain on approach charts. Five groups called out the highest obstacle or terrain during the verbal briefing (Groups 4, 12, 13, 14, and 15). Participants in Groups 14 and 18 mentioned they especially liked seeing the terrain in color.

4.1.3.5 Minimum Safe Altitude (MSA)

Participants use the MSA to get a general idea of whether high terrain or obstacles will be a factor for the IFP. The MSA is consistently available on approach charts. It represents a safe altitude that is at least 1,000 ft above the highest man-made obstruction (FAA Aeronautical Information Manual (AIM), 2015, page M-4). Participants in all groups (except the informal Group 2) mentioned the MSA in their verbal approach briefings, highlighting this information.

Participants would like to see similar information reliably on arrivals and departures. Currently, it is only on some Jeppesen charts and it is not shown on the FAA charts. In fact, the MSA is not part of the IFP specification for arrivals and departures; it is only specified for approaches. The MSA indicates terrain within a specified range of a landmark, such as a conventional navigation aid located on or near the airport. Because SIDs and STARs are not drawn to scale, it may be difficult to determine how far along the route the MSA applies.

The MSA was inconsistently available on our test arrival and departure Jeppesen charts:

- The KORRY STAR did show an MSA.
- The BLZZR SID and FRDMM STAR did not show an MSA.
- The EDETH ONE SID did show an MSA, but it did not appear on EDETH TWO.

Because of the inconsistent availability of the MSA on SIDs and STARs, participants were sometimes confused when it was not shown. Five groups looked for the MSA, or would like to see the MSA, on SIDs (Groups 1, 5, 7, 13, and 18). Six groups looked for the MSA on the STARs (Groups 1, 4, 7, 9, 13, and 19). Group 1 was so attuned to looking for the MSA on arrivals that they even noticed that the MSA on KORRY was drawn in an atypical location. They expected to see it in the top right, but it was in the middle of the top half of the page.

Participants who looked for the MSA but did not find it on the (FRDMM) arrival or the BLZZR or EDETH TWO departures (Group 1, 5, 7, and 13) said they would look for an approach into that airport to find the MSA. This strategy could be problematic; participants may not realize that the MSA can be based on different reference ground-based navigation aids for different approaches.

4.1.3.6 Text and Graphical Route Representations of SIDs and STARs

The text route description is in a table titled "Initial Climb Table" for SIDs and titled "Landing Notes" for STARs. All groups used the text route description for SIDs and STARs (except Group 10, who sometimes used it, and Group 5, who used it for SIDs but not STARs). The graphical depiction is in the main plan view of the chart. All groups used the graphical depiction.

Some participants expressed a subjective preference for either the text or graphical route representation, but there was no clear preference overall. Both representations are useful in different ways and at different times.

Most of the participants started to review the IFP from the text, especially for SIDs. After reading the text version of the runway transition on a SID, participants then looked at the graphic to review the rest of the route. Group 2 specifically mentioned that they depend upon the Initial Climb table more than the graphic. They said the picture can be confusing, and that they need to know that the route in the Initial Climb table matches the route in the FMS.

The initial climb table on SIDs has separate rows for each runway transition, so the pilot can easily look up the transition based on the assigned runway. Using the runway-specific row is easier and may be less confusing than using the graphical depiction (which might have crossing transitions, as in BLZZR). For example, Group 18 mentioned that on the BLZZR SID taking off on Runway 22R, the graphic appears to show a heading of 216° to KIRAA, but, the text description clarifies that the correct path is heading 216° to TJAYY, not KIRAA (see Figure 2).

An interesting side comment from Group 19 was about how pilots review charts when using an electronic chart viewer on an EFB. The participant indicated that, on an electronic chart viewer, he would first look at the full chart to get a sense of the direction, then he would zoom into the text of the SID initial climb description, then he would zoom into the graphic view. This is consistent with our findings from participants who were using paper charts for the study.

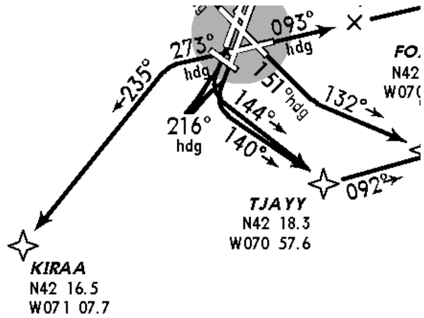


Figure 2. Close up of BLZZR SID.

For STARs, participants usually started with the graphic route to verify the path in the FMS then they reviewed the landing notes in the text. The arrival may be assigned before the landing direction or runway, which is one reason to begin with the graphic. However, one participant in Group 12 said he started with the runway transition and worked backwards to the start of the arrival. He first looked at the landing notes, then the graphic. On KORRY, Group 9 noted that the information in the text box is only useful if you are using VORs for the conventional procedure, but they would be using lateral navigation (LNAV) instead, so the text landing information was not useful.

4.1.3.7 ATC Communication Frequencies on SIDs and STARs

All groups used ATC communication frequencies on SIDs regularly, except Groups 4 and 11, who used them sometimes. Groups 3 and 8 said that the PDC may or may not give the ATC frequency; the PDC may assume you have the frequency from the chart or the ATIS. Group 6 mentioned that the Tower Control might not state the Departure Control frequency, assuming that the pilot has it already.

Four groups used ATC communication frequencies from the approach charts (Groups 12, 15, 17, and 19). Four groups say they do <u>not</u> use these (Groups 7, 11, 14, and 16). These groups said they would get the frequencies from ATIS or from a handoff. Group 18 would use only the tower frequency, if there is just one listed. The other 10 groups did not mention whether they would use the ATC communication frequencies from approach charts.

ATC communication frequencies are not generally used for STARs. Pilots expect that ATC will hand them off to the next frequency or that they will get the frequency from the ATIS. The frequencies on the chart are a backup and would be used if there were a problem with the handoff (e.g., lost communications, or a stuck microphone).

4.1.3.8 Climb Gradient Table

The climb gradient table on the chart is in feet-per-distance (a percent gradient). The pilot has to convert this value to feet-per-min in order to monitor the aircraft's vertical rate in real time. Ground speed is the intervening variable, which can vary by aircraft type.

Most groups reported using the climb gradient table (Groups 1, 2, 3, 8, 11, 12, 13, 14, 15, 16, 17, 18, and 19). Some groups say they do <u>not</u> use this (Groups 5, 6, 7, and 10). The climb gradient table is less useful to pilots who have other sources of data about aircraft performance (e.g., from Dispatch, other company-specific guidance or on-board software for computing performance data). Some participants felt their aircraft had excellent climb performance, and so were less inclined to check the climb gradient table.

Two groups (Groups 4 and 9) reported using the climb gradient table occasionally, for airports near terrain, to check on engine-failure procedures. Group 18 said they would use the climb gradient table particularly if they knew that it was based on avoiding terrain, rather than for meeting ATC requirements.

4.1.3.9 Takeoff Obstacles

Four groups said they would use the takeoff obstacle information on the chart (Groups 1, 12, 13, and 17) usually in order to plan a safe return to the airport in case of engine failure. Several participants said they would use it sometimes, depending upon terrain, weather, or familiarity (Groups 3, 4, 7, 8, 11-one pilot, 15, 16, 18, and 19). The participants in Group 11 were split on this item.

Several groups said they do not use this information (Groups 2, 5, 6, 9, 10, 11-one pilot, 14). Groups 2 and 6 did not consider smaller obstacles mentioned in takeoff obstacles (e.g., towers, poles, and ships in the harbor) to be a primary threat. Group 5 said they look at the MSA instead. Group 9 said they do not fly at airports where engine performance would be an issue.

4.1.3.10 Use of Notes

Most notes are grouped into a box on the briefing strip, but some notes are on the plan view or profile view.

There was a lot of variation in the use of notes, between groups, between IFP types, and even between individual IFP briefings. We could only observe whether the participants discussed or mentioned any particular notes; if they read a note silently and did not talk about it, we did not know whether they had read it. For example, Groups 8 and 13 said they skim the notes individually and only review them in detail if unfamiliar with the IFP or if they are looking for particular issues. Group 2 mentioned they were trained to read all the notes on the approach briefing strip, but that was not the case for the briefing strip notes on SIDs and STARs.

Most groups used the notes sometimes, but many used them inconsistently. Participants reviewed the notes in the briefing strip more reliably for approaches than for SIDs and STARs. Some notes in the briefing strip are useful and well understood (e.g., GPS required). It appears that pilots make tradeoffs about whether they should or should not review the notes carefully because of their mixed utility.

Only Groups 1, 12, 17, and 18 consistently reviewed all notes in the briefing strips for approaches, SIDs, and STARs. Other groups consistently reviewed notes for approaches (Groups 2, 3, 4, and 11). Three groups (Groups 5, 6, and 13) mentioned the notes only inconsistently or infrequently. Groups 9 and 10 consistently verbally briefed only the bold notes on SID and STAR briefing strips. Group 7 said they briefed the approach off the FMS and did not say whether they look at the chart briefing strip notes.

On the plan view, some notes are visually highlighted (e.g., with bolding, or capital letters) while others are not. Notes are sometimes scattered around, making them hard to find and making the chart appear cluttered. Clutter created by notes and their placement is discussed in Section 4.3.13.2.

Types of notes on the plan view include:

- Holding speeds (e.g., on KORRY)
- Lost communications information (e.g., on EDETH TWO)
- Equipment requirements or limitations (e.g., on the Boise RNAV (RNP) Z)
- Which transition to expect (e.g., on KORRY enroute transitions)

Sometimes, the chart producer adds notes to the plan view. Jeppesen, for example, includes limited distance information on arrivals and departures, which were not drawn to scale. Jeppesen will also sometimes highlight unusual aspects of the IFP (e.g., speed restrictions on the BLZZR or the nonstandard/custom note on EDETH describing it as a "stepped climb"), but these modifications are not always useful. These types of notes are discussed in Section 4.3.14.

One participant wondered whether notes could be more useful if they informed pilots about local operations (e.g., "expect to slow" at this point). However, this type of note could be difficult to implement because the local operations and chart updates could be out of sync.

4.1.3.11 Full Lateral Course

Most groups did not mention the full lateral course during the verbal briefing, though they sometimes mentioned the initial or final heading. Only Group 1 reviewed the entire lateral course consistently during their verbal briefings. Groups 6, 11, 13, 16, 17, and 18 mentioned only the initial and/or final headings during verbal briefings. Groups 14 and 15 used the distance information along the lateral course to check climb/descent rates, but did not use the directional information. Groups 1 and 7 noted that they could identify a radius-to-fix (RF) leg on the RNP AR approach by its lack of directional information along the route.

Two groups (Groups 8 and 10) said they do not use lateral course and another group said they would not verbally brief the lateral course (Group 12). Other groups did not discuss use of the lateral information from the chart (Groups 2, 3, 4, 5, 7, 9, and 19).

4.1.3.12 MOCA/MEA on SID Transitions

Some groups do not use the segment altitudes for obstacle clearance and radio reception (Groups 6, 7, 8, 9, 12, 14, 15, 16, and 18). Some groups did not mention (Groups 1, 2, 3, 5, 10, 11, 17, 19), but they did not appear to use these altitudes. One group (Group 4) said they would use MOCA and MEA altitudes only for awareness and another (Group 13) only for single-engine operations.

4.1.3.13 VOR Cross Radials on KORRY

No groups said they would use the VOR cross radials to fly the KORRY arrival. Although KORRY is a conventional procedure, they fly it using LNAV. Most groups explicitly said they do not use the cross radials (Groups 1, 2, 3, 7, 9, 10, 11, 14, 15, 16, 17, 18, and 19), while other groups did not mention them (Groups 4, 5, 6, 8, 12, and 13).

4.1.3.14 Waypoint Latitude/Longitude

Eight groups said they do not use latitude/longitude data (Groups 4, 8, 10, 12, 14, 15, 16, and 17). Some groups did not mention this (Groups 1, 2, 3, 5, 6, 7, 9, 11, 13, and 18). Group 19 said that they would use latitude/longitude data while flying over the ocean on the North Atlantic tracks. Latitude and longitude data do not appear to be useful for operations over the continental United States.

4.2 Feedback on IFP and Chart Difficulties

In this section, we present the feedback from participants regarding difficulties with IFPs and charts. Examples of the various difficulties are provided in Section 4.3. Here we just present an overview of the direct participant feedback. Section 4.2.1 covers responses to the question about IFP difficulty and Section 4.2.2 reports on what participants said about chart difficulty. In Section 4.2.3, we discuss how these responses were analyzed. Section 4.2.4 presents a case study to illustrate IFP and chart difficulties, comparing participant responses about the two arrival procedures, FRDMM and KORRY.

4.2.1 Reported IFP Difficulties

We gathered responses to the question "What makes a procedure difficult?" from each of the groups into one file. Then we interpreted each issue from each group to determine what its topic and subtopic were. Sometimes a response could be interpreted in different ways, so we included all interpretations as possibilities.

We observed examples of many, but not all, of the difficulties that participants mentioned during the study. Some of the difficulties mentioned by participants were not observed during the study due to the task fidelity and method limitations discussed in Sections 3.4.3 and 3.6. For example, participants sometimes talked about what would happen under different circumstances, such as different weather scenarios, with different aircraft automated systems, or with different IFPs that they had flown. They also sometimes reported what they thought pilots in general might do or consider in certain situations.

The full list of topics and subtopics we identified from the raw data about IFP difficulties is given below. The topics are loosely ordered by how frequently they were mentioned. However, even issues that were mentioned by only one group are important because our goal was to develop a comprehensive list of factors. The group(s) that mentioned each topic is/are listed in parentheses after the topic name.

- IFP design
  - Constraints (Groups 1, 2, 6, 7, 8, 9, 11, 12, 14, 15, 16, 17)
  - Variable descent angles in different segments of arrival (Groups 14, 16)
  - Vectors as part of the IFP (route discontinuities) (Groups 2, 10)
  - Prohibited airspace in the vicinity (Group 7)
  - Inability to pronounce waypoint names (Group 5)
  - Holds (Group 15)
  - Notes (Group 8)
  - Connection from STAR to IAP (Group 10)
  - Transitions (Group 9)
  - Step-downs on approach outside of glide slope intercept (Group 9)
- ATC intervention
  - Non-specific (Groups 5, 7, 8, 9, 11, 13 18)
  - Late change (Groups 1, 2, 10, 13, 18)
  - Speed amendments (Groups 3, 4, 6)
  - Unpublished change (Groups 2, 13, 14)
  - Confusing instructions (Groups 3, 19)
  - Unplanned vectors (route discontinuities) (Groups 2, 10)
  - Unpublished restriction (Group 3)
  - Runway change (Group 4)
  - Interaction of ATC intervention with aircraft performance (i.e., difficulty completing the request) (Group 4)
- Aircraft features
  - Availability and quality of automated systems (e.g., availability of coupled VNAV and/or autothrottle, lack of well-functioning trusted automated systems, or monitoring requirements) (Groups 2, 6, 10, 13, 15, 17)
  - Availability of GPS (Group 19)
  - Performance limitations (Group 15)

    - Other necessary aircraft-related tasks (Group 18)
- Deviation from "normal" (Groups 2, 7, 10, 12)
- Traffic (Groups 2, 10, 13, 18)
- Weather (e.g., visibility, storms, or winds) (Groups 2, 4, 10, 13)
- Terrain (Groups 4, 7, 12)
- Distractions (Groups 2, 7)
- Fatigue (Groups 2, 18)
- Lack of familiarity with area (Groups 7, 8)
- Type of ATC Environment (e.g., high or low air traffic density, multiple versus single airports served) (Group 14)
- ATC transition (i.e., handoff between facilities) (Group 10)

Interestingly, there were a few items we thought participants might bring up that they did not mention. Specifically, participants said they had no difficulties with the lack of scale on the SIDs and STARs, and they do not care about the length of the SID or STAR. The lack of scale on the transitions was not noticed by most of the groups. In a conversation with Group 11, they said the SID ended when they reached their cruise altitude and the SID's route distance was not important.

We also searched for comments related to flying a route with "closely spaced" waypoints because that has been a point of discussion for IFP designers. However, this issue was not mentioned as a response to the final question about what makes an IFP difficult. Four IFPs in the study had examples of closely spaced points: FRDMM, EDETH, BLZZR, and the Boise RNAV (RNP) Z approach. On BLZZR, the closely spaced points created visual clutter but participants said that they could clear up the visual clutter by looking at the navigation display. On EDETH, Groups 3, 12, and 19 noticed that there were restrictions that were closely spaced in time, which might require some extra attention. On FRDMM, Group 12 mentioned visual clutter from the close placement of waypoints on the chart. Groups 6, 12, 15, 17, and 18 just noticed the closely spaced waypoints. They may have checked their timing or questioned the need for them to be so close together, but they did not anticipate any difficulty flying the IFP. For the Boise RNAV (RNP) Z approach, Group 11 mentioned that they would configure the aircraft early in anticipation of the last few closely spaced waypoints and Group 1 mentioned visual clutter as a result of the close spacing. Groups 3 and 4 noticed the spacing on this approach, but did not anticipate taking any special action.

4.2.2 Reported Chart Difficulties

We gathered responses to the question "What makes a chart difficult to use?" from each of the groups into one file. Each issue from each group was interpreted separately to determine what its topic and subtopic were. The resulting list of topics is given below. As in the previous section, the topics are loosely ordered by how frequently they were mentioned, but even topics mentioned by only a single group are important to consider.

- Variation in depictions/lack of standardization in depictions
    - Nonstandard depiction (Groups 1, 7, 15, 17, 19)
    - Note placement (Groups 3, 5, 6, 8, 12)
    - Placement of elements other than notes (Groups 4, 8, 11, 19)
    - (Lack of) consistency (Groups 2, 7, 8, 11)
    - Unfamiliarity with the chart depiction (Groups 6, 10)
- Clutter
    - Non-specific (Groups 5, 7, 9, 16, 17, 18, 19)

    - Too many elements, some unnecessary (e.g., latitude and longitude) (Groups 3, 6, 8, 10, 14, 16, 18)
    - Legibility (not readable) (Group 13)
    - Redundant (unnecessary) notes (Group 8)
- IFP-design related elements
    - Number of transitions per chart image (Group 16, 18)
    - A lot of notes (Group 3, 8)
    - Altitudes shown for segments of an approach instead of at a waypoint (Groups 4)
    - Route variation leading to nonstandard chart depiction (Group 7)
    - Ambiguity (Group 1)
- Pages
    - Large (e.g., fold-out) (Group 7)
    - Multiple (Groups 3, 4)
- Chart graphical composition
    - Route graphic depiction hard to read (Group 16)
    - Element-specific (e.g., should highlight an item) (Group 4)
- High information density (Group 6)
- Missing notes related to typical operations (Group 8)

Also, participants felt that, while a chart that depicts crossing transitions may appear to be cluttered, it did not bother them because they can see the path they will fly on the navigation display and FMS CDU clearly. This is similar to how participants said they handled the visual clutter on charts created by closely spaced waypoints mentioned above.

4.2.3 Analysis of Participant Feedback on IFP and Chart Difficulties

In reviewing the data presented in Sections 4.2.1 and 4.2.2, we realized that participants did not always clearly separate complexity that was created by the IFP from complexity created by the chart. We had to analyze the issues that participants brought up and decide how to categorize the source of difficulty.

We also realized that participants reported many issues that were outside the control of IFP and chart designers. They were actually describing operational complexity factors that made it difficult for them to fly the IFP as published. We pulled out five such factors and list them in Table 6 along with examples. Many of the operational complexity factors mentioned by participants were *not* in the model of IFP complexity described in Table 1 (Section 2.3). The data we obtained create a richer picture of the normal daily disturbances that impact the IFP.

The IFP and chart difficulty issues that remain after separating out operational complexity factors could sometimes be categorized as either a IFP design issue or a chart issue, but not always. Some of the issues were related to both IFP design and charting. In many cases, an IFP design issue was the source of a chart design issue.

Operational Complexity Factor	Examples
ATC Intervention	• (Late) route amendments • Unpublished restrictions • Vectors (unplanned)
Aircraft	• Lack or unreliability of automated systems • Performance characteristics
Crew	• (Standard) expectations • Fatigue • Communication style • Distractions • Local area familiarity • Familiarity with different types of IFPs
Operator	• Independence vs. dependence on Dispatch • Clarity and consistency of PF/PM roles in reviewing procedures
Environment	• Terrain • Traffic • Weather (e.g., unusually strong tail winds along an arrival or instrument meteorological conditions during an approach) • Prohibited airspace

Table 6. Operational complexity factors for IFPs.

4.2.4 Case Study

It is instructive to consider a case study of two STARs tested in the study, FRDMM and KORRY, which illustrate various design issues and tradeoffs. The charts for both are in Appendix B.

FRDMM is a relatively new RNAV STAR Optimized Profile Descent procedure (OPD) for Washington (KDCA). It has 11 waypoints on its common route, three more waypoints on the "landing north" transition and four waypoints along the "landing south" transition. It has many more altitude and/or speed constraints than KORRY. There are 14 constraints on FRDMM versus 8 on KORRY. FRDMM also has many types of altitude constraints, including "at" altitude constraints, "at or above" altitude constraints, an "at or below" altitude constraint, window-altitude constraints (with upper and lower altitude boundaries), and co-located speed and altitude constraints. The Jeppesen depiction of FRDMM fits on one full-size landscape page. The FAA graphic depiction of FRDMM uses two standard size pages, also landscape. The common route is on the first page and the runway transitions are on the second page.

KORRY is an older conventional STAR (not RNAV) with seven "at or above" altitude constraints and one hard "bottom" altitude with an "at" speed (an implicit 250 kt and 10,000 ft at KORRY). The IFP has been used for many years in the busy La Guardia, New York (KLGA) airspace. The common route of KORRY has 14 waypoints from SMYRNA to PROUD. The COLIN enroute transition adds five waypoints and the AGARD enroute transition adds two waypoints. The Jeppesen depiction of KORRY is a full-page landscape view with an inset in the upper left corner showing the two enroute transitions. The FAA depiction of KORRY is on a standard size page, in the portrait orientation. Crews familiar with KORRY mentioned that its published speeds are often modified by ATC, especially during high traffic density conditions ("pushes").

We asked participants to compare the difficulty of KORRY with FRDMM. Groups 1 and 5, who fly relatively new aircraft with advanced avionics, felt that it was easier to fly FRDMM than to fly KORRY.

They said it was easier to have altitude or speed constraints at each point than to *not* have altitude and speed directives. However, 11 of the 18 groups we asked felt that KORRY was easier to fly than FRDMM. They cited having fewer hard altitude constraints, no speed restrictions, and no window-altitude constraints as reasons why KORRY was easier. Groups 4 and 11 thought the workload for KORRY and FRDMM were equal. They said that while FRDMM had more restrictions, those restrictions were programmed into the FMS, which reduced their workload. They also pointed out that both FRDMM and KORRY ended with vectors, making them similar.

Groups 3, 13, and 18 had mixed opinions and pointed out pros and cons for each arrival. The pros for KORRY were that it had fewer restrictions and a less rigid path. The cons for KORRY were that it had an inset on the chart for the enroute transitions and it was therefore more difficult to understand the path visually. The pro for FRDMM is that the chart is visually less complicated without the inset; the route flows naturally across the page. The cons for FRDMM were that there were two landing transitions (a branch in the route) and that it looked (visually) more cluttered because of the speed restrictions and an "excessive" number of altitude constraints.

4.3 Examples of IFP and Chart Difficulties

IFP design complexity has many sources. To get a more complete understanding of IFP design complexity, we combined data from Sections 4.2.1 and 4.2.2 (which were reported in response to a direct question at the end of the study) with data from other sections of the summary files. These other data captured the discussion during the whole interview, not just the response to the last two questions. Below is a list of the other sections in which we found relevant data:

- In-flight Techniques
  - Waypoint Verification
  - Window-altitude constraints
  - Late Routing Changes
  - VNAV Operations
  - Navigation Database
- General Procedure Comments
- Specific Procedure Notes

In analyzing this broader set of data, we identified more areas of IFP design difficulty than the participants themselves reported. We also found examples and supporting details for some of the issues that the participants did mention at the end of the study.

We also looked at the raw data on the difficulty of using charts. These data are more difficult to interpret because we had to look beyond what the participant said to understand the underlying factors. Chart difficulties reported by participants were often related to elements of the IFP design. These include notes, variation, altitudes, and waypoints names. As discussed in Section 2, this is a reflection of the IFP complexity on the charting depiction.

It is useful to think about the examples of subjective IFP and chart difficulties in terms of how they could be resolved. Some of the issues could be addressed by changing the IFP design. Some may require changes to the chart design. Still others require a joint understanding of how IFP design affects the chart design, so that the IFP could be altered to make it easier to depict in a standard layout.

4.3.1 Ambiguity

Ambiguity is in the eye of the beholder. What may be clear to one pilot may not be clear to another. The source of the ambiguity could be the IFP design, or it could be a lack of training about how to interpret the IFP design, a lack of understanding about how an aircraft system would work under particular conditions, or an unclear chart depiction. One example of ambiguity that we are aware of is the case of SIDs with published constraints that are above the top altitude. Some pilots, at least initially, do not realize that the top altitude is their clearance limit because the constraints on the charts appear to be part of the required (and therefore "cleared") IFP. This ambiguity is being addressed through changes to IFP designs, ATC procedures, and pilot training.

Our data identified two cases where some participants felt the IFPs or charts in the study were unclear, the Denver approach and the EDETH departure, discussed below.

4.3.1.1 Denver ILS/LOC RWY 35R RNAV Transitions

The Denver approach tested in the study (ILS/LOC RWY 35R) has RNAV transitions to an ILS procedure. This was unfamiliar to many of the participants in the study. They saw some pros and some cons for this type of design. Group 15 said they liked having definite guidance going from the STAR to the transition to the approach. This is helpful when ATC is busy and does not have time to communicate with each crew. They felt that the transitions reduced ambiguity. The alternative, to have controllers give each aircraft vectors, could create ambiguity in their view. Similarly, Group 16 liked that the IFP lined the aircraft up with the final approach fix in case they lost communication with ATC.

However, there was some confusion for the corporate pilots from Groups 17 and 18. Group 17 treated the transition as separate from the approach. They were not sure whether ATC would give them a separate clearance to cross the initial approach fix and join the ILS, or whether once they were cleared for the approach, it cleared them for both the RNAV transitions and the ILS. Consultation with subject-matter experts in industry leads us to believe that ATC will issue only a single clearance for the full approach, including transitions.

Group 18 was confused about the altitudes on the RNAV transitions. Were they MEAs, mandatory altitudes, or were altitudes assigned by ATC? Because these altitudes were on the published IAP they guessed they could descend to those published altitudes, but they thought it was unusual to fly an approach where you descend to the MEA. Discussions with subject-matter experts outside of the participant group indicate that the correct interpretation is that the altitudes on the chart are MEAs, and that VNAV will generate the actual altitudes to be flown.

Group 18 also noted that the different entry gates to each transition had different mandatory altitudes and speeds at the initial approach fix. This was important information that they would highlight, and they would expect ATC to highlight it as well. However, in practice, the mandatory altitudes at the initial approach fix might be clearer because their altitudes and speeds match constraints on the STAR termination point.

4.3.1.2 Salt Lake City EDETH SID Constraints

The EDETH departure tested in the study can be described as a climbing left U-turn to avoid terrain. Participants said their natural inclination in this situation is to climb first to avoid the terrain then increase their speed to exit the busy terminal area quickly. Figure 3 shows the flight path for the initial climb. There are a number of constraints. First, at BUCCO, there is a mandatory 230 kt speed constraint combined with an altitude constraint to stay below 10,000 ft. The aircraft must cross SCANT above 10,000 ft, cross HIDUT at 11,000 ft, and cross TOOLE above 13,000 ft; Speed is not specified at any of these points. Then at MUSAW, the mandatory speed is 250 kt at an altitude below FL230 (but above 13,000 ft).

The speed restriction at MUSAW is unusual because pilots expect to be at normal climb out speeds above 10,000 ft, which would be well over 250 kt. Group 18 described this as a “trap” during their briefing. Group 15 pointed out that the 230 kt mandatory speed at BUCCO also limited them. They could not use the Flight Level Change (FLCH) vertical mode of their FMS because they are not able to change the default speed for FLCH on their aircraft, which is 240 kt.

The sequential speed constraints at BUCCO and MUSAW also created some confusion. Participants in Groups 16 and 19 did not know when they were allowed to start speeding up after BUCCO. They felt the speeds between BUCCO and MUSAW were ambiguous. In contrast, the note “resume normal speed after MUSAW” was useful in reducing ambiguity.

Participants described some strategies they would use to reduce ambiguity for EDETH. Group 5 said that although flying 250 kt above 10,000 ft was a nonstandard speed constraint it would be in the FMS, and they were sure that it would be handled correctly. In Group 4, one participant was not sure whether the constraint was in his FMS. He would check and alter the constraints if necessary. A different participant in Group 4 (who flew a different type of aircraft from the same manufacturer) said that he may have to manually set the speed in the autoflight system after BUCCO to keep the climb rate going, or the plane may nose down to increase speed. Participants in Group 16 were unsure about when to speed up after BUCCO and said they would ask ATC.

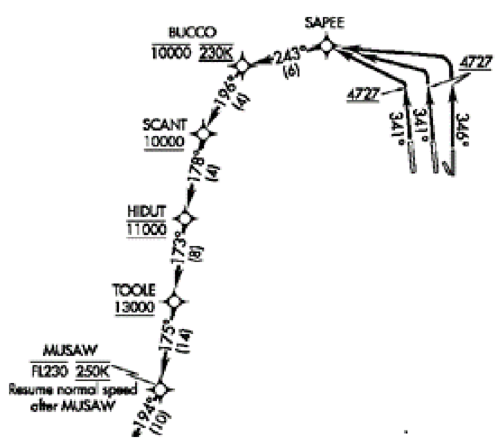


Figure 3. EDETH SID initial climbing U-turn.

4.3.2 Route Variability

Some new IFP routes are unlike any other designs that pilots have seen before. There is a great deal of variation between flight paths because they are highly customized for the local airspace and terrain. Variation in routing yields variation in chart design as charts respond to the need for a unique depiction that does not fit with the standard layouts. For example, Group 7 mentioned that the Boise RNAV (RNP) Z depiction with a “blow up box” (the zoomed in section shown on the second page) was a nonstandard depiction, which made the chart difficult to use.

IFP routes can vary so much that it can be hard to establish a pattern for their review; each IFP has to be reviewed as if it were completely unfamiliar. With ILS approaches, pilots used to be able to depend upon one IFP being much like another. They could review a few key parameters and know that they understood the IFP quickly and easily. That is no longer the case. Now pilots must become familiar with different types of IFPs in each airspace. For example the Denver airspace uses several RNAV transitions to ILS approaches, so the pilot who flies routinely to Denver will become familiar with that type of approach. The pilot is most likely to learn this during "on-the-job-training," not in a simulator or training class, especially given the rapid introduction of new airspace and IFP designs.

4.3.3 Visually Noncontiguous Paths

The Scottsdale RNAV (RNP) approach shown in Figure 4 is an unusual looking IFP. It has two feeder routes that are both too long to fit within the normal scale of the plan view. These feeder routes are drawn in insets that connect to the main portion of the approach in the plan view.

The IAP shown in Figure 4 (in the FAA format) is not only unfamiliar, it is also difficult to understand how the path flows. This is an example of a visually noncontiguous path. The unusual chart depiction is the result of an IFP design that has longer feeder routes than standard. The pilot has to mentally connect the routing from SWIRL to ONELE in the upper left inset with the routing beyond ONELE in the plan view. Similarly, on the lower right, the pilot has to connect that feeder route to the FURST waypoint in the plan view.

Although we did not discuss the Scottsdale approach with participants in this study, there is a similar visual discontinuity in the KORRY chart that we did discuss (see Appendix B). KORRY has a large inset box in its upper left corner. This inset is the result of the design of the KORRY IFP, which does not fit the image in a standard layout. Participants mentioned that the inset box was a source of difficulty (see Section 4.2.4). They had to examine the chart depiction carefully to determine whether the route began in the main graphic and continued into the inset or whether the route began in the inset and continued to the main section. (The latter is correct.) Group 5, who was familiar with the Denver airspace, mentioned that several arrivals there use insets too.

The Denver approach chart tested in the study has a similar visual discontinuity between the left and right panels on the chart, which threw some participants off. In reference to the Denver approach, a participant in Group 1 said he had to "break the code" of where they were coming from. Participants found the discontinuity on the two-page format of the Boise RNAV (RNP) Z approach especially unusual. That chart has a dashed box to indicate the area drawn at a zoomed-in scale on the second page of the chart.

The need for nonstandard inset boxes has a domino effect; the inconsistencies multiply. For example, on the older (now out of date) Boston KRANN arrival, the IFP began in the main chart section and the runway landing transitions were in the inset. But KORRY has the enroute transitions in the inset, a different flow. The pilot has no convention to follow across the two depictions. The full-page Jeppesen depiction of the ANTHM TWO arrival into the Baltimore-Washington International airport (KBWI) is even more unusual; it has two "insets" that are of equal size, with a dividing line across the middle of the page, making it even more confusing for the pilot to determine where the route begins and ends. Interestingly, participants with flight experience in Europe had less difficulty with the novel chart layouts and visual discontinuities because they said they have seen similar split charts for European airports.

Many of the chart variation issues, such as the use of insets, arise from the limitations of creating a static terminal chart that has to be shown on one page (or one screen). In some cases, Jeppesen uses foldout pages or multiple pages to show the IFP. These can create other problems, such as reading information along the fold line or manipulating a large piece of paper in a small flight deck. The FAA uses only a single page size, so long arrivals and departures are more likely to be split across two pages. This is the case for the ANTHM and FRDMM arrivals. FAA approach charts all fit on one standard size page, so they have inset boxes.

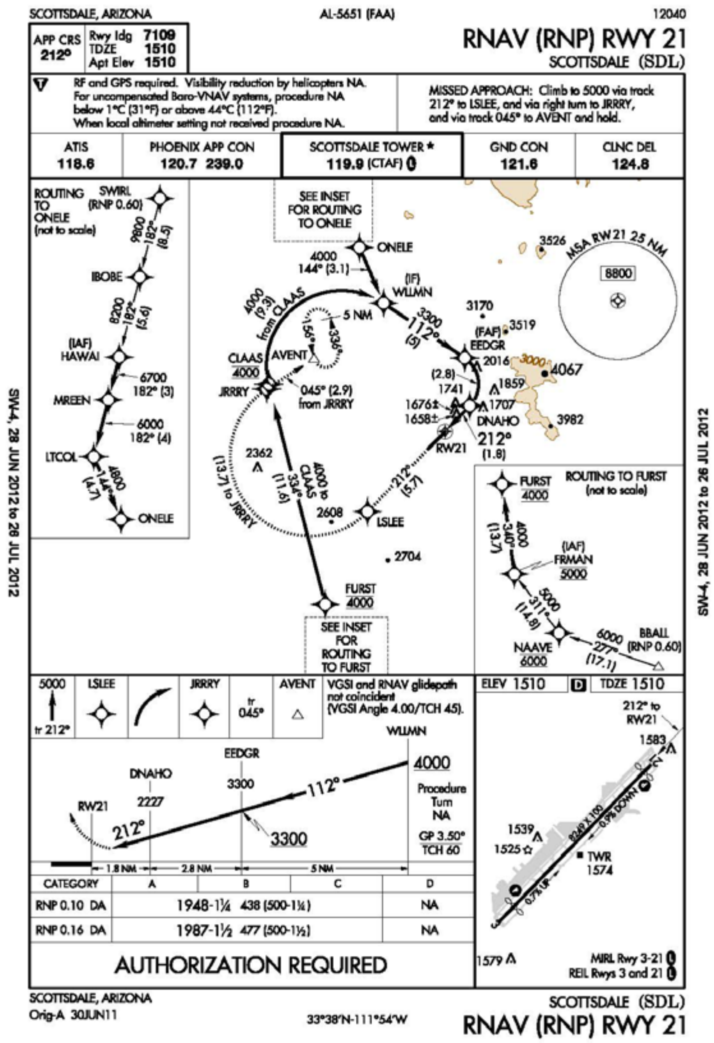


Figure 4 Scottsdale, Arizona RNAV (RNP) approach to Runway 21 with insets and long feeder routes.

4.3.4 Transitions and Feeders

All but one IFP in the study (the Boise RNAV (GPS) approach) had transitions in one form or another. On approaches, a "feeder" is a flight path to the final approach fix. On arrivals and departures, the term "transition" is used to represent a similar idea. A transition is a flight path that leads to or from a common point on the IFP.

FRDMM has two landing transitions (north and south), which split at ALWYZ. KORRY has two enroute transitions (i.e., transitions from a point in the enroute airspace to the common route), which meet at SMYRNA. The Denver approach has four RNAV transitions (or feeders) to the ILS, which all meet at DORRY, the intermediate fix. The Boise RNAV (RNP) Z approach has eight feeder routes into the runway; they meet at HOBSI. The BLZZR departure has seven runway transitions, which all meet at BLZZR. The

EDETH departure has two different runway transitions and three enroute transitions, with EDETH as the common point.

Transitions are part of the IFP design and they have to be charted. Transitions therefore add difficulty both in terms of the route itself and in terms of the visual depiction. They also contribute to IFP variability, mentioned earlier (Section 4.3.2). Transitions increase the mental work for the pilot because they add decisions that the pilot has to make. The pilot has to determine, for example, what is the final altitude *for the transition* he/she expects to use? Different transitions may have different clearance limits. On FRDMM, one transition goes to 8,000 ft while the other goes to 6,000 ft. The pilot also has to think through the likelihood of getting a runway change that would alter the transition or feeder. If ATC issues a runway change there are already many steps the pilot has to do to reconfigure the FMS and the Mode Control Panel (MCP). Changing the transition correctly adds even more steps. So, the expectations about runway changes will affect whether the pilot decides to enter the route into the FMS early (to complete the task and move on to other tasks) or late (to allow for route amendments).

Visual depictions of transitions can also require nonstandard chart formats, such as the noncontiguous paths mentioned in Section 4.3.3. Even when the paths are contiguous though, transitions can result in higher visual density in some areas, such as on the BLZZR chart. FRDMM also has a high visual density in the Jeppesen chart right at the point where the two transitions split, which created some confusion for participants (see Figure 5). The transitions actually split at ALWYZ, not at FRDMM; this is shown clearly in Figure 6, the FAA depiction, and in Figure 7, the text description of the transitions from the Jeppesen depiction. However, pilots (and perhaps chart designers as well) expect that the arrival is named for the end of the common route. The name of the FRDMM arrival is different from the recommendation in the FAA Joint Order in effect at the time, 7100.9E. The FRDMM waypoint (which by convention is bolded and capitalized in Figure 5) is actually on the transition for landing to the south. Group 13 brought this inconsistency to our attention. They wondered why FRDMM was not named the ALWYZ arrival. In part because of the naming convention, and in part due to the way the graphic is drawn, just nine groups briefed the transition split at ALWYZ, while seven briefed the split (incorrectly) at FRDMM.

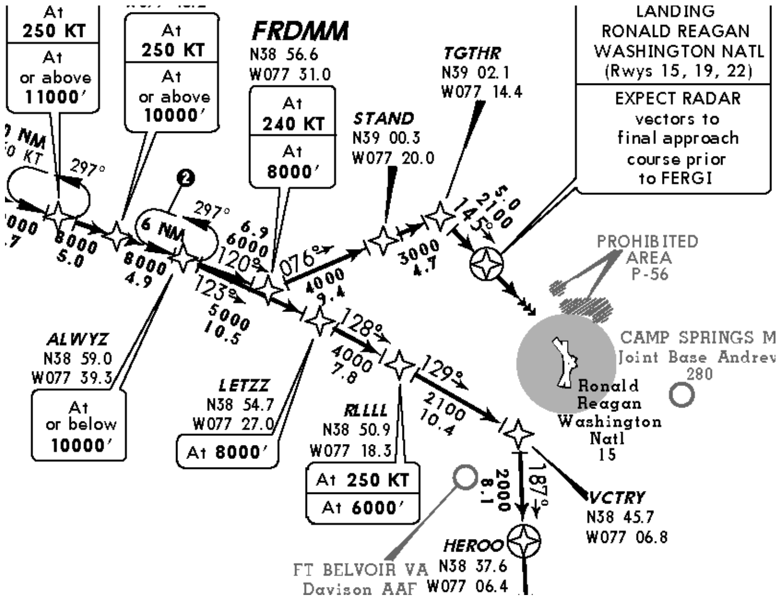


Figure 5. Transition split on the Jeppesen chart for FRDMM.

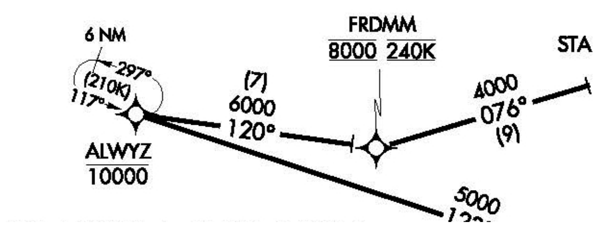


Figure 6. Transition split on the second page of the FAA chart for FRDMM.

RWY	LANDING RONALD REAGAN WASHINGTON NATL
1, 4, 33	From over ALWYZ on track 123° to LETZZ, then on track 128° to RLLLL, then on track 129° to VCTRY, then on track 187° to HEROO, then on track 187°. EXPECT RADAR vectors to final approach course.
15, 19, 22	From over ALWYZ on track 120° to FRDMM, then on track 076° to STAND, then on track 076° to TGTHR, then on track 145° to FERGI, then on track 145°. EXPECT RADAR vectors to final approach course prior to FERGI.
LANDING DAVISON AAF	
From over ALWYZ on track 123° to LETZZ, then on track 128° to RLLLL, then on track 129° to VCTRY, then on track 187° to HEROO, then on track 187°. EXPECT RADAR vectors to final approach course.	

CHANGES: Procedure revised, renumbered.

Figure 7. Landing notes from FRDMM. The text confirms that the transitions split at ALWYZ.

4.3.5 Holds

Holds are not flown frequently. Still, participants reviewed holds for missed approaches carefully, especially if they assumed poor weather. For arrivals, it was not common to brief the holding pattern locations. Only Group 1 briefed these for STARs. However, participants were aware of when they were more likely to get holds on arrivals if they were familiar with the airspace. For example, Group 5 mentioned that they have been issued holds at PROUD on KORRY even in good weather.

When issued, holds are a source of pilot workload, especially if the hold is for a missed approach, and in poor weather. Pilots would have to reprogram the FMS (if there is time), or plan a manual entry, set up the MCP, then hit the proper heading, speed and altitude at the correct point in space. Even an arrival holding pattern can create significant workload if it is issued late. Group 15 said that if they only have 10 miles to set up a hold, their workload would spike if they were not expecting the hold. They said they "may step down the automation ladder to verify the initial turn," meaning that they would start their initial turn for the entry before reprogramming the FMS.

Even if holds are not issued, pilots may pay extra attention during certain operations to be prepared for a last minute hold clearance. For example, Group 1 mentioned that they would listen to ATC communications during the FRDMM arrival into Washington, DC to hear whether other aircraft were being issued holds on the arrival, so that they could prepare as early as possible.

The visual depiction of multiple holding patterns on arrivals can increase the visual complexity of the chart, making it appear cluttered and difficult to read (cf. the FAA depiction of KORRY in Appendix B). Because of tight spacing near the route, these holding patterns may also need leader lines (on FAA charts) or ball notes (on Jeppesen charts) for additional information, such as the maximum holding speed. Sometimes the maximum holding speed can be slower than the mandatory speed along the route, creating potential for a significant deceleration (see Section 4.3.11).

4.3.6 Waypoint Names

Waypoint names are specified in the IFP design. They cannot be modified after the IFP is defined. They may or may not get much attention when IFPs are created, but they are "the face" of the IFP to the pilots. The names are how pilots remember the individual IFPs and develop knowledge of and familiarity with the airspace. Waypoint names are also key elements of the IFP briefing because pilots read the names *aloud* to confirm that the FMS route matches the route on the chart. When a clearance is amended and the crew needs to brief a new IFP under time pressure, they still check the waypoint names one at a time.

Participants liked waypoint names that had local references and were different from others on the same IFP. But, we observed that participants often stumbled when pronouncing the waypoint names during the briefing. If they did not stumble, they just pronounced them in different ways. For example, some participants slowed down the normally quick briefing process to pronounce the SEPII waypoint on FRDMM as "September Eleventh," which has many syllables. Other participants read it quickly as "seppy." In other words, some participants read the two letter I's as the number "11" while others did not. Anecdotally, the local ATC pronounces it "seppy."

Participants also had difficulty with waypoint names such as ICUJY and IDOCY on the Boise RNAV (RNP) Z approach, which are not pronounced easily. Participants spelled out these waypoint names, which again required several syllables and slowed down the briefing. Waypoints without vowels (e.g., BLZZR) were subject to interpretation (Blazer or Blizzard?). This sometimes started sidebar conversations during the briefing. Group 5 participants said that it was harder to manage names that all sound (and may look) the same, such as waypoints that begin with the same letter (e.g., Dashy, Drats, Ditse, Dorry, Deane, and

Drumm on the Denver approach). It can be easy to pick the wrong one on the CDU, especially in turbulence. They wanted waypoint names that were distinct from each other. Finally, Group 5 also mentioned that GPS identifier points used in the western United States, which have letters and numbers (e.g., "KA270"), were error prone and more difficult to use. This feedback matches results from a human factors analysis of the Navigation Reference System waypoint nomenclature (Burian, Pruchnicki, and Christopher, 2010). This report also concludes that it is easy to forget, confuse, and transpose characters when using alphanumeric identifiers.

4.3.7 Number and Content of Notes

We need to distinguish the content of notes from their number and placement. We discuss the placement of notes in Section 4.3.13.2, under the Chart Clutter heading because participants perceived notes that were placed in a seemingly haphazard way as clutter. However, some notes have important content. The important notes might be mixed in with notes that are less useful so the pilot may miss them. Sometimes there are so many notes that pilots may miss information even if they are trying to read everything.

Important notes, which are needed to fly the IFP properly, are more common on PBN IFPs. For example, on the Memphis BLUZZ ONE RNAV STAR, a note specifies the east-west runways (9 and 27) are accessed from the landing south transition, which is not necessarily something a pilot unfamiliar with the airport would know. The landing north transition is only used for runways 36L/36C/36R, not 9 and 27. This is the last of several notes, many of which may be less useful (e.g., radar required). This particular issue, about the depiction of STAR terminus points and what approaches they join, is being addressed by the ACF (Appendix F, ACF issue paper 15-01-293). A separate issue paper submitted to the Instrument Procedures Group discusses the complexity of content in speed restriction notes on SIDs and STARs (Appendix F, ACF issue paper 16-02-328).

Participants used or mentioned notes inconsistently because they may not be useful for a variety of reasons (see Section 4.1.3.10 more on the general use of notes). Notes that were not useful were considered to be "clutter," which is generally discussed in Section 4.3.13. Participants mentioned the following reasons why they might not use a note:

- The note is standard and therefore uninformative. It may have been useful when the note was new and nonstandard. For example:
    - FRDMM, Note 6. "MAINTAIN last ATC assigned altitude until cleared to "descend via the FRDMM TWO", then comply with altitude restrictions as published.
    - KORRY, Note 2. "MAINTAIN last assigned altitude until cleared to "Descend via the KORRY THREE". Then comply with altitude restrictions as published."
- The note does not affect pilot actions and is for general awareness only. For example:
    - BLZZR, Note 3. "RNAV 1." Because there is no action to take, some participants ignored this note. Some participants read the note because it was bolded, but then later could not explain its importance. See Section 4.5.1 for more about this note.
    - BLZZR, Note 5. "Departure heading/RNAV tracks/vectors are predicated on avoiding noise sensitive areas. Flight crew awareness and compliance is important in minimizing noise impacts on surrounding communities." Some participants felt that this note was for legal purposes only because they already know the airport is near a city.
- The note is not relevant to the operations. These notes do not affect pilot actions. For example:
    - BLZZR, Note 6. "Rwys 15R, 22L/R: Do not exceed 210 KT until 520'. Most commercial aircraft are not capable of exceeding 210 kt until they are well over 520 feet altitude. See Section 4.3.13.3 (p. 51) for more about this note.

- The note pertains to “others” to inform them of a restriction that does not apply to the pilot’s aircraft or situation. For example:
  - Note 4 “For turbojets only” on BLZZR, Note 1 “Applicable to turbojet aircraft only” on KORRY, and Note 4 “Turbojet aircraft only” on EDETH. These notes are useful to aircraft that are *not* turbojets so they know they are not qualified for the procedure. They are not useful to aircraft that *are* qualified.

4.3.8 Vectors

Vectors allow ATC real-time flexibility to work around traffic and other (non-physical) constraints as needed for each flight. Some arrivals, such as FRDMM and KORRY, end in vectors issued by ATC to the runway. Groups 2 and 10 equated vectors with route discontinuities in the FMS. In general, pilots seek to clear route discontinuities in the FMS.

The Denver approach in the study does not require vectors to the ILS. The entire approach is coded in the navigation database so the route from the RNAV transitions through the ILS has no discontinuity. Group 15 commented that the transitions on this approach reduce ambiguity about their flight path, whereas the alternative, vectors from ATC, add ambiguity. This is because the flight crew does not know what vectors to expect, and they have to respond quickly to each vector issued.

Interestingly, Groups 4 and 18 said that would ask for vectors if they needed to offload workload to ATC (see Section 4.4.4). In this case, vectors allow the crew to stop relying on the FMS to fly a pre-programmed path. This can relieve workload because the crew can focus on resolving an FMS issue, or they can respond to another issue entirely without monitoring the route in the FMS.

4.3.9 Prohibited/Restricted Airspace

IFPs are designed to avoid prohibited and restricted airspace. These areas may be one of the reasons for RF legs or other detours that may seem unnecessary at first glance. The FRDMM arrival has an example of this because the White House/National Mall/Capitol (P-56A) and Naval Observatory (P-56B) are well known prohibited areas near the airport. All but three groups in the study (Groups 3, 6, and 9) briefed the prohibited areas and Group 7 mentioned that prohibited airspace was a factor in overall IFP difficulty.

4.3.10 Constraints

Participants had much to say about flight path constraints, and vertical constraints in particular. First we discuss how participants verified waypoints along the flight path (Section 4.3.10.1). Next we consider how participants monitored whether the aircraft was going to meet a constraint or not (Section 4.3.10.2). Sometimes, participants said they had to actively manage the aircraft to be able to meet a constraint. We discuss their strategies for managing constraints in Section 4.3.10.3. The last three sections here, Sections 4.3.10.4 , 4.3.10.5, and 4.3.10.6 cover issues with constraints on arrivals, constraints on departures, and constraints on approaches, respectively.

4.3.10.1 Verifying Waypoints

We asked the participants: “Which waypoints would you verify as you flew over them? What do you do to verify a waypoint?” To verify a waypoint means to ensure that the aircraft is crossing it correctly. This question elicited a wide range of responses. Participants often pointed out that, because they checked all the constraints and waypoints during the route entry into the FMS and the chart briefing, active verification of crossing waypoints is not a critical task in flight, especially when there are no constraints on the waypoint. For example, on departure, participants said they do not verify the waypoints after they have passed all points with published constraints, even if they are still on the published route, which could continue for some distance along an enroute transition.

Some participants said they actively communicate that the constraint is being met. They verbalize either the current constraint as they pass it, or the next constraint to be met. This helps to keep both crewmembers aware of the flight path. An audible callout is less intrusive than a visual callout (e.g., pointing to the waypoint on the navigation display as they fly over it). When time is tight, however, participants said they might skip the verbalization, a strategy for shedding workload.

4.3.10.2 Monitoring Constraints

Monitoring a waypoint is different from "verifying" it. Monitoring is an active on-going process, typically reserved for tasks where pilots are responsible for the end result, but automated systems handle much of the work.

Most participants said they do not monitor lateral position actively. Some said they monitor waypoints along the lateral path passively by scanning various displays. For example, some participants said that each crewmember independently watches the moving navigation display to be sure they "stay on the magenta line." Pilots have tools to monitor the lateral path (e.g., course deviation indicator), but our participants said they trust the lateral navigation system. Many participants said they would not monitor lateral position during a short departure runway transition up to an altitude before turning direct to a waypoint because those segments go by so quickly (cf. BLZZR).

Participants said that they do monitor waypoints carefully when there are vertical flight path constraints. As one participant from Group 8 said, every restriction is "an opportunity to screw up." Participants were concerned that they would be cited for a violation and be disciplined (e.g., with a suspension of their certificate) if they missed a constraint. Under most situations, the threat of legal action for missing a constraint is more on their mind than a safety concern such as a collision with another airplane or terrain, for which they have other flight deck systems and ATC support.

To monitor whether the aircraft will meet a vertical constraint, participants report that they often use a visual tool on the navigation display or other primary flight display (e.g., a "green arc" on Boeing aircraft or a "hockey stick" on Airbus aircraft). It is also possible to configure the navigation display to show the actual numerical value of the speed or altitude constraint. Then the flight crew can check that the aircraft is leveling off or changing speed appropriately. Participants said they could also monitor the waypoint constraints on the CDU, watching the page update as constraints are met. Many CDUs (or similar displays) are capable of showing target crossing-altitudes for window-altitude constraints. However, most participants said they do not actively monitor this value. They consider it "nice to have" but do not rely upon it.

More engaged participants said they monitor constraints by confirming aircraft parameters, such as the altitude entered in the autoflight system. This value is shown on the Flight Mode Annunciator. Some participants said they also confirm the mode they have selected for vertical navigation (FLCH versus VNAV). They are especially careful when using FLCH for an "at or below" altitude constraint.

Participants flying one particular aircraft for a major airline in our study made a distinction at 10,000 ft. Below 10,000 ft altitude, they manage speed manually, which means they enter speed constraints in the MCP (or similar control panel) as needed. Above 10,000 ft, the FMS manages speed, without pilot manual entries. As a result, they were especially aware of the altitude at which the constraint occurs. This is not an aircraft limitation; it is an operator restriction.

Some participants said they are especially careful to monitor window-altitude constraints. For example, a participant from Group 8 told us he would “stare at the altimeter” for all of the window altitudes, to be sure they were meeting the constraints. This level of attention was deemed necessary because of past experience with window-altitude constraints that were not met by their aircraft’s automated systems.

An interesting aspect of all these monitoring options is that the flight crew must constantly evaluate and decide how critical it is to monitor the waypoint, and when to begin the monitoring. This constant evaluation is, in itself, a monitoring task. For example, some participants gave higher priority to monitoring “at or below” altitude constraints and window-altitude constraints. Group 2 mentioned that they focus on monitoring altitudes over monitoring speed; their explanation was that ATC is more likely to notice an altitude deviation than a speed deviation. Other participants were especially wary of waypoints with co-located speed and altitude constraints. Some participants said they start monitoring constraints earlier if they know there are several constraints to be met in a row, as on FRDMM, or they will monitor earlier if there is any doubt whether they can meet the constraint.

4.3.10.3 Managing Constraints

As mentioned earlier, participants highlight the constraints to be met in their briefings (Section 4.1.2). Unexpected or unusual constraints get extra scrutiny and briefing time. There may be additional discussion of how to set up automated systems to handle atypical constraints.

Even with advance preparation, participants said that they sometimes have to manage waypoint constraints actively in flight. In other words, pilot intervention may be needed to meet the constraint. The type of intervention required, and when that intervention is executed, are a function of the aircraft’s flight characteristics, its available automated systems (VNAV and/or autothrottle), as well as the trust that pilots place in the automated systems. For example, participants said that window-altitude constraints require especially careful monitoring and active management if ATC amends speed or routing. Other participants said they had to remember to control speed through the autoflight system, which requires cognitive workload to remember to do this task.

Participants mentioned a number of different interventions that may be necessary. For example, the pilot might need to deploy speed brakes during descent if the aircraft is not slowing and descending as needed. The FMS may declare “drag required” during an arrival, but the participants said they make an independent assessment of the situation; sometimes they agreed with the FMS and sometimes they did not. Having to deploy speed brakes was viewed differently by different participants. Some did not see deploying speed brakes as a penalty while others did. Sometimes the penalty is “an emotional penalty,” the feeling that if they had managed the flight better, they would not have needed the speed brakes (Group 12), and sometimes the penalty is to the passengers, with buffeting and discomfort. Although there were some participants who try not to use the speed brakes, Group 4 said that there comes a point where you may need to use them.

Another example of pilot intervention that participants mentioned was to change or create constraints in the FMS. During the briefing, if the crew anticipates difficulty descending during an arrival, they may change an “at or above” constraint to an “at” constraint. Or if they see a co-located speed and altitude constraint, they may create a waypoint earlier in the route to separate the speed from the altitude constraint.

Participants said they also consider company policies and the potential for high or low energy states as they consider how to meet constraints that might be difficult for their aircraft or in the current wind conditions. For example, some speed constraints require changing the FMS settings so that the aircraft can fly faster than economy speed.

Participants said they make choices about how and when to use coupled and advisory VNAV to meet vertical flight path constraints. Some said they use VNAV only for descents, not for climb. Corporate pilots in Group 18 used coupled VNAV in advisory mode and chose not to couple the VNAV with the autopilot. They said that the human pilot is better at flying the vertical path than the autopilot because their aircraft autopilot had a noticeable lag.

We heard that using VNAV does not fully relieve the pilot because it creates additional setup and monitoring. As one participant said, “Automated flight is great, but it’s like trying to use cruise control in traffic. At some point it’s better just to fly the plane.” Participants flying two different aircraft types noted that it was not worth the extra effort to set up the VNAV for the Boston BLZZR departure, which does not have altitude constraints on some runway transitions.

4.3.10.4 Constraints on Departures

The SIDs in the study had relatively few constraints. BLZZR had two “at or below” speed constraints and two “at or above” altitude constraints. EDETH had one mandatory altitude constraint, two “at or above” altitude constraints, and two mandatory speeds co-located with “at or below” altitude constraints. We did not count initial turns from the runway (altitude-based turns) as constraints. There were no window-altitude constraints in our two sample SIDs.

For the “at or below” speed constraints on BLZZR, participants reported that these constraints would require monitoring. However, the speed constraint might be irrelevant if the aircraft would not normally be going that fast by that point.

For “at or above” altitude constraints on both departures, participants reported that these could be a problem on days with hot weather or a heavy aircraft. They said that “at or below” altitude constraints, in general, might be overshot if the aircraft has strong climb performance. There were no comments about the mandatory altitude constraint on EDETH. For the two constraints on EDETH with both a mandatory speed and “at or below” altitude, some participants said it was not clear to them when they could speed up again after the constraint (see Section 4.3.1.2).

Some participants mentioned that it is more difficult to manage speed on departures than arrivals. They said that pilots have more control over aircraft configuration changes when descending because they can extend flaps, landing gear, or use speed brakes to slow down. On departure, aircraft configuration changes do not help to manage speed.

4.3.10.5 Constraints on Arrivals

The arrivals in the study, KORRY and FRDMM, had several constraints of different types, as described in the case study (Section 4.2.4). We gathered participant feedback on these constraints, and also general input about constraints on arrivals.

Overall, we expected that automated systems such as VNAV and autothrottle would alleviate pilot workload on arrivals with speed and altitude constraints. And, in fact, one participant in Group 8 who had flown FRDMM on different aircraft types said that FRDMM was easier to fly with VNAV than without VNAV. He felt that FRDMM was designed for aircraft that had VNAV, even though VNAV is not an FAA requirement to fly that arrival. However, other participant feedback indicates that not all VNAV and autothrottle systems are equivalent; some work better than others. When participants did not trust their VNAV system, crew workload increased.

Also, VNAV and the autothrottle system need to work well together and this was not always the case. We heard about one aircraft model on which the automated systems had trouble meeting co-located speed and altitude constraints in particular. If both constraints could not be met at the same point, the FMS might only meet the altitude constraint and miss the speed constraint. Some participants said they anticipate this problem and address it by creating an extra waypoint in the FMS to separate the co-located constraints. Other participants said they might ask ATC for relief from one of the two types of constraints (either speed or altitude).

We also explored the workload induced by the lack of an autothrottle. We expected that it would be easier to fly an arrival such as FRDMM with VNAV and autothrottle than with only VNAV and no autothrottle. However, participants who flew aircraft with VNAV and without autothrottle said that if the arrival is flown as designed, workload from the lack of autothrottle is manageable, especially with regular practice. In other words, when operational complexity (e.g., from traffic, weather, and ATC interventions) is not a factor, the workload of flying FRDMM without autothrottle is reasonable. Group 11 characterized the lack of autothrottle as creating “medium” workload. Group 3 characterized the additional workload as “a little.” Group 13 described lack of autothrottle as “some workload…but small changes are not a big challenge.”

Participants also had a lot of general feedback about managing altitude constraints on arrivals, some of which was covered earlier (Section 4.3.10.3). Participants said that mandatory altitude constraints take more work than “expect” altitudes, but they (i.e., mandatory constraints) are the simplest type of altitude constraint relative to other types. With regard to “at or above” altitude constraints on arrivals, participants said that it may be hard to slow the aircraft. Some of them said they try to stay at the bottom of the permitted altitude range. They might also change the “at or above” altitude constraint to an “at” constraint (at the bottom altitude) to help manage the aircraft energy state on descent.

There was an “at or above” altitude constraint followed by an “at or below” altitude constraint on FRDMM. Some participants said they would check for a steep descent angle and related passenger discomfort in this type of situation.

Window-altitude constraints received the most critical feedback from participants. Some said they would change the window constraint to an “at” altitude (using the bottom of the window) in the FMS so that it would be easier to slow down the aircraft. They said that VNAV tries to keep the aircraft at higher altitudes for fuel efficiency, but that can be a problem for aerodynamically clean aircraft that have trouble slowing and descending at the same time. Participants also said that window-altitude constraints require careful monitoring. Some participants did not trust their automated systems to be able to meet window-altitude constraints. Some participants said that broad window-altitude constraints are harder to meet than narrow window-altitude constraints because of the potential for a steep descent to the next constraint. For one particular aircraft type, participants said it could go into a strange oscillation mode with window-altitude constraints. The aircraft sometimes could pitch up and down to meet consecutive window-altitude constraints, and pilots would have to intervene to stop this behavior.

4.3.10.6 Constraints on Approaches

We evaluated three different approaches in the study, two from Boise and one from Denver. Issues related to vertical flight path constraints on these approaches are discussed in Sections 4.3.1.1 and 4.3.12. However, Group 9 mentioned a problem that we did not see in our sample charts, the issue of step-down fixes outside of the glide slope intercept. This situation happens on the ILS to runway 6 at Teterboro, NJ (KTEB) and on the ILS to runway 4R in Chicago, O’Hare (KORD). The FAA has issued guidance to pilots on this (FAA, 2011). The information letter explains that altitude constraints outside the glide slope intercept are based on indicated altitudes, which vary with outside temperature, whereas the glide slope does not vary with temperature. Pilots who intercept and follow the glideslope from before the glideslope intercept point may not always meet the step-down fix restrictions. On hot or high-pressure days, the step-down altitudes will be higher than they are on cold or low-pressure days. So, while joining the glideslope early may satisfy the step-down fix restrictions on a cold day, it may not meet the restrictions on a hot day. Smith (2013) also discusses this issue in a magazine for pilots.

4.3.11 Energy Profiles

Energy profiles must be matched between two adjoining IFPs (e.g., an arrival and approach) or within segments of an IFP. Speeds and altitudes may both need to be matched. For example, participants said that sometimes arrival procedures left them high and fast at the start of an approach.

On KORRY and FRDMM, there is a potential problem matching speeds on holding patterns (which may or may not be flown) and speeds along the path. Participants noticed (and briefed) holding speeds on KORRY. There is a 210 kt holding speed on KORRY (see chart in Appendix B) that applies to several waypoints, some of which are well above 10,000 ft, where the aircraft might be going faster than 250 kt. If ATC issued a hold, the aircraft would have to slow to 210 kt, which could be difficult depending on its previous speed. Similarly on FRDMM, at PLDGE, there is a mandatory speed constraint at 280 kt, but a holding speed of 250 kt (see Figure 8).

Participants familiar with the GIBBZ TWO RNAV STAR into Dulles airport (KIAD) in Virginia (see Figure 9) said it was complex because of a sudden change in the vertical descent rate between segments. Groups 14, 15, and 16 brought this IFP to our attention even though we did not review it formally in the study. There is a steep descent between IGGGY ("at or below" 14,000 ft) and MOSLE (mandatory altitude of 11,000 ft and mandatory speed of 250 kts), which requires the aircraft to lose up to 3,000 ft in 7 miles. The mandatory speed of 250 kts at MOSLE adds to the difficulty of the task, because the aircraft must descend without speeding up. Normal descents require the aircraft to lose 1,000 ft per 3 miles. Then, between MOSLE and THZMN (mandatory altitude of 7,000 ft) there is a shallow descent (4,000 ft over 22 NM). This significant change between segments requires the aircraft to reduce its rate of descent suddenly, which can be a surprise to the flight crew, particularly on aircraft with only advisory VNAV.

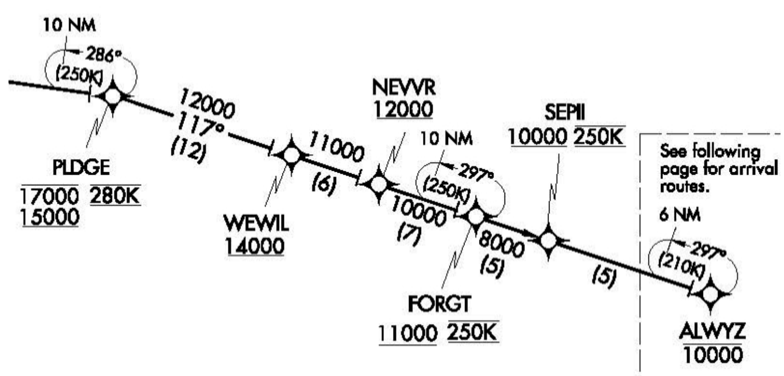


Figure 8. Excerpt from FRDMM arrival showing mismatch between mandatory speed at PLDGE (280 kt) and the holding speed at PLDGE (250 kt).

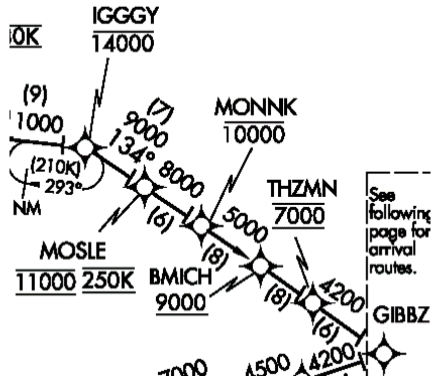
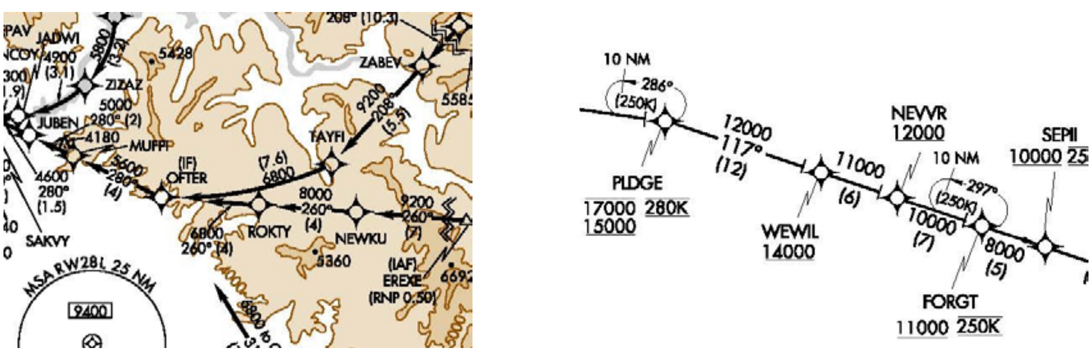


Figure 9. Excerpt from the GIBBZ TWO RNAV STAR into Dulles (KIAD) showing a steep descent rate from IGGY to MOSLE, then a sudden change to a shallow descent from MOSLE to THZMN.

4.3.12 Inconsistencies between SIDs, STARs, and IAPs

Some participants noted the lack of consistency between altitude specifications on SIDs and STARs versus IAPs. Approaches show altitudes along the route segment (Figure 10a), while SIDs and STARs show altitudes at a point (Figure 10b). Approach altitudes have always been specified this way, but four crews (Groups 4, 5, 6, and 8) commented that it was odd to see altitudes along the segments instead of at the points on the approach. They wanted the approach altitudes to be called out similar to the altitudes on SIDs and STARs. Group 4 was unsure what altitude to be at when crossing NEWKU on the Boise RNAV (RNP) Z approach as a result of their confusion.

It is not clear whether changing the altitudes on an approach segment is a simple matter of drawing them differently on the chart depiction, or if the actual altitude values would change if they were computed for the point instead of along the segment. Changing how altitudes are specified on approaches might result in a new procedure specification, which would have to be verified.



(a) (b)

Figure 10. Excerpts from Boise RNAV (RNP) Z approach (a) and (b) FRDMM RNAV STAR showing different altitude-specification conventions.

Another inconsistency between SID and STAR charts versus IAPs is how mandatory speeds are identified. This is illustrated on the Jeppesen Denver approach chart used in the study (see Appendix B). Although the RNAV transitions are drawn like a SID/STAR at first glance, the speed and altitude constraints are drawn differently here. On a SID/STAR constraint, Jeppesen uses a callout box and the abbreviation KT for knots (e.g., At 280 KT on FRDMM). On the Denver approach, however, the RNAV transition has text next to the waypoint for mandatory speeds and altitudes (e.g., “MANDATORY 9,000 At 210 KIAS”). Text descriptors were used on approaches because they take less space than the callout boxes used on SIDs/STARs. This is an historical inconsistency that will be corrected in the new Jeppesen chart format, where constraints will be drawn the same way on SIDs, STARs, and IAPs.

Interestingly, Group 18 expected to see terrain on the Denver chart because it is an approach. They were surprised not to see terrain on the RNAV transition (not-to-scale) portion. They knew the terrain was present because they were familiar with the local area.

4.3.13 Chart Clutter and Visual Density

Crews often mention “clutter” when they discuss why charts are difficult to use. However, that label by itself is not useful. One reason is because sometimes clutter is confused with the visual density or busyness of the chart, which cannot be fixed by the chart producer. Sometimes the IFP design just requires a lot of data (e.g., many constraints or many notes). Sometimes however, the graphic designer can improve visual density, for example, by changing the scale of the depiction (on a SID or STAR) or by adjusting the placement of notes to clarify areas with a lot of elements.

Another reason that “clutter” is not a useful label is because what may be useless to one crew is important to another. Saying that the chart is “cluttered” really means, “I can’t find what I need.” However, as explored in Section 4.1.3, the data that crews need vary. In this section, we present results related to data that crews did not use often, or which they felt added clutter.

Beyond the need for data, or the amount of data, there are some other reasons why participants brought up the issue of clutter. The clutter might be because they felt the chart was illegible, because information was scattered about making it hard to find, or because there was too much information or unnecessary information, all of which made it difficult to find useful information.

4.3.13.1 Illegibility

There are several potential reasons why a chart might be considered illegible. A small font will be difficult to read, of course. But, eyesight varies even among normal pilots due to age-related far-sightedness. In other words, older pilots usually need reading glasses and have more trouble with small fonts. Using an EFB can alleviate this issue because pilots can zoom in easily, but it creates other problems, such as losing track of data that are off-screen (Chandra and Kendra, 2010; Chase and Hiltunen, 2014).

When elements on the chart overlap (e.g., crossing lines for transitions), readability can be impaired because it may not be clear what elements apply to a given path. However, participants said they have alternate ways to view the route, on their navigation display or CDU Legs page, which can clear up confusion related to crossing paths. Pilots often look at the FMS and/or navigation display when briefing (see Section 4.1.2).

Sometimes pilots confuse readability with the inability to find information that is not “prominent.” This is the typical reason that pilots ask for certain information to be highlighted visually (through bolding or coloring, etc.). However, prominence of data depends upon the context and expectations of the user. Prominence of one element can be enhanced, but may come at the expense of de-emphasizing a different element. It is unreasonable to expect every element of the chart to be prominent, by definition.

Poor lighting or fatigue can also reduce the legibility of a chart, but this is beyond the scope of chart design.

4.3.13.2 Placement of Notes

The use of notes in the briefing strip and in the plan view was discussed earlier in Section 4.1.3.10. The number and content of notes was considered in Section 4.3.7. Here we consider the placement of notes.

The FAA charting convention for SIDs and STARs is to label all notes "NOTE:" and to group them. This makes it easy for pilots to find them. But, sometimes there are a lot of notes, creating a block of text that is too large to fit into the available space. Also, the font for notes is uniform, so there is no visual distinction between different types of notes, which might increase the sense of clutter.

Jeppesen handles notes and their placement differently from the FAA. Notes are placed based on the type of information and where the note applies along the route. General text notes might appear in any open space on the chart. For example, FRDMM has notes with direct distances from the termination of the transition to the airport. These notes are in the center of the main graphic, so they are easy to find here, but on other charts they could be easy to miss if they were in unexpected locations.

If notes were placed in a consistent location, they would be easier to find. There was an attempt to indicate something about the content of a note by its location, but it is not clear whether pilots understand and use these conventions (see Appendix F, ACF issues papers 01-01-137 and 13-02-312 on Equipment and Procedural notes).

Jeppesen marks other notes with a visual symbol (such as a ball with a letter or number inside, a "ball note"). The symbol is placed along the route where the note applies, but the text of the note appears elsewhere. Ball notes are usually located near the path at the point where they apply, but some apply to more than one point, or they cannot be placed near where they apply because space is tight. An example is the holding-speed ball note on the KORRY arrival. There is a maximum holding speed of 210 kt at EDJER, HOLEY, RBV, and PROUD. The ball note, denoted by a small B is in the lower right-hand corner in the open white space rather than next to each waypoint. Unless participants were familiar with this note from past experience with KORRY, they often took extra time to find it.

4.3.13.3 Unnecessary Data

Participants mentioned that there is unnecessary information on the chart. They gave, as examples, notes that do not pertain to their aircraft or notes that appear obvious (e.g., noise sensitive areas near cities), which were discussed in Section 4.1.3.10. Sometimes they mentioned other parts of the chart, such as the climb gradient table, or the takeoff obstacle notes. Group 8 even mentioned that the lateral course information on charts is clutter; they do not use it because they expect it to be correct in the navigation database.

We reviewed the data to find out what chart elements the different groups did or did not use. Results about data that participants *did* use were provided in Section 4.1.3. Participants approved of some of the information on charts that is not directly part of the IFP design (e.g., shaded terrain and communication frequencies for SIDs).

Sometimes participants discussed their rationale for why certain information was not useful. For example

- VOR cross radials on KORRY are not useful because the participants use lateral navigation, not VOR navigation to fly the arrival.
- ATC communication frequencies on approaches are not used because participants said they expected to be handed off from one controller to the next. Communication frequencies on STARs are not used often for the same reason. However, communication frequencies on SIDs

are used because participants said they need to know how to initiate contact with the Departure controller (especially if they do not receive a PDC with the Departure control frequency).

- MEAs and MOCAs are rarely relevant to jet aircraft that typically fly at much higher altitudes.

However, sometimes it is difficult to identify whether information is truly irrelevant to the operation because it might be used in rare circumstances. For example, one group mentioned that the “RADAR REQUIRED” note that appears on some approach charts is useless to them because they do not fly in non-radar environments. The “RADAR REQUIRED” note indicates that at least a portion of the IFP is not navigable with ground-based navigation aids, but this does not affect aircraft that are flying with RNAV. Would this note be useful to someone else, under other conditions? Who is the target audience for it and when would it be useful? No group admitted to using latitude and longitude information on the Jeppesen charts. Most groups who mentioned the latitude-longitude data thought of this as clutter. However, the study participants were all US-based; some foreign carriers may still use latitude and longitude data.

We also found that participants treat terrain information differently based on their aircraft and the environment. For example, many participants noted that EDETH had steep climb gradients. They looked at climb gradients especially carefully if they had concerns about single-engine procedures in the aircraft. The climb gradient table gives a picture of the terrain in the vicinity of the initial climb. However, pilots have to convert the units of the climb gradient table (feet per NM) to a climb rate in feet-per- minute that they could use in real time. This is an extra step. Some participants have access to flight-performance calculation software in the flight deck. These pilots could check the aircraft performance in reference to the climb gradient if needed. Participants who did not use the climb gradient tables viewed them as clutter or unnecessary information. For more on the use of the climb gradient table see Section 4.1.3.8.

The least important terrain data to most groups in this study were the takeoff obstacle notes. These were generally the lowest and, therefore, least important obstacles. As one airline participant in Group 2 put it, “Put something I might hit. We have bigger issues if we hit an object 12 feet from the departure end of the runway.” Only some groups used the takeoff obstacle notes, some of the time (see Section 4.1.3.9).

Speed restrictions that are not operationally relevant (see Figure 11 and Figure 12) were also considered to be “unnecessary.” The aircraft in our study could not achieve 210 kt at such a low altitude of 520 ft. Figure 12 shows a maximum holding speed that participants said they would not choose to fly because it is not fuel efficient. The speed restriction is defined by the IFP designer to limit the turn radius for the holding pattern to ensure obstacle clearance. These restrictions may be relevant to a small group of special users (e.g., military jets), but they are not useful for commercial operations. The FRDMM arrival also shows repeated speed constraints at multiple waypoints on the descent. Some participants thought the repeated speeds were nice but not necessary unless you can enter the arrival from different points.

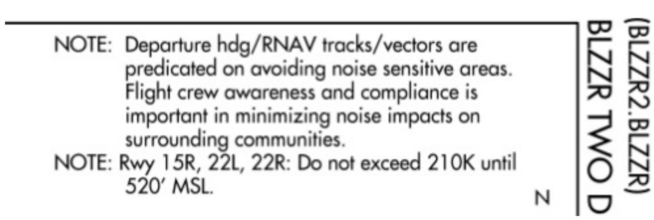


Figure 11. Speed constraint on BLZZR note.

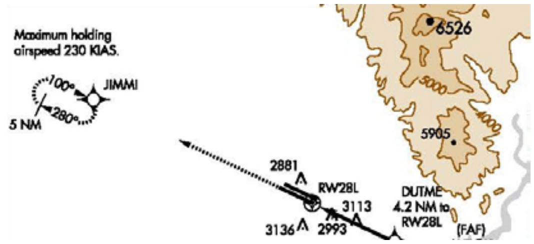


Figure 12. Maximum holding speed on missed approach procedure for the Boise RNAV (RNP) Z approach.

4.3.14 Chart-Specific Depiction Issues

Chart designers arrange visual elements on the chart. Jeppesen refers to this task as *chart composition*. The designer places standard sections (e.g., briefing information) on the page and arranges elements within sections (e.g., where the notes are within the plan view or where the callout boxes are relative to the route). The chart designer also decides what font to use, what bolding or visual highlight to use, what thickness of line, and other such graphical choices within conventions established by the chart producer. Adherence to standard conventions helps avoid problems with chart composition. However, sometimes pilots may not recognize the conventions. (For example, Jeppesen uses dashed lines to indicate a transition route, but Groups 8 and 10 did not know this convention.) Effective chart composition can help the pilot to find information quickly and interpret the chart accurately. However, design choices may not always be optimal for every situation, leading to some inefficiency.

Chart composition is affected by the IFP design, although less so than other chart design issues. The overall orientation of the IFP and its design (e.g., number of transitions and number of constraints) affect:

- How the IFP is arranged on the page (e.g., portrait or landscape, with insets or not)
- What size page is used (standard, full size, or foldout etc.)
- What space is available for other data elements

For example, the landing or initial climb notes text box for STARs and SIDs can be in any corner of the page. All the information is grouped, but the pilot may have to look in each corner of the chart until he/she finds the box. The corner where the text is placed varies to maximize space for the graphic route depiction.

We identified chart-specific depiction issues by reviewing the following sections of the summary files:

- Briefing Techniques
- Chart Format Comments
- Specific Procedure Notes

We identified three types of chart composition issues: arrangement of chart elements, inconsistencies, and nonstandard chart-producer notes.

There were two specific examples of chart element arrangement issues, one on EDETH and the other on FRDMM. The Jeppesen version of the EDETH SID in this study (which is primarily oriented north-south) is drawn such that the long transitions have extended space and require a full size page. In a paper binder, this requires a fold out page that opens out horizontally. To make the briefing information easy to read in the paper format, it is along the "top" of the page in the binder. For EDETH, the effect is that the briefing information is rotated 90 degrees from the flight path (see Appendix B). In the paper version, the pilot can easily take the chart out of the binder and rotate it for ease of reading. However, rotating the view can be trickier on an EFB. It might be especially difficult if the EFB is mounted and cannot be physically rotated. The mismatched orientation of the graphic and the briefing information bothered some participants more than others.

On FRDMM, the chart element arrangement issue was the position of the callout boxes. Group 16 noted that the callout boxes were on different sides of the flight path, and pilots might make a mistake with that depiction. This is probably because the pilot might scan just the one side of the path with the most callout boxes, missing the one box on the opposite side at PLDGE.

One example of a charting-specific inconsistency from our data was discussed earlier, regarding BLZZR. Some pilots were confused by the depiction of the runway heading departing runway 22L/R (see Section 4.1.3.6 and Figure 2). The leader lines are confusable with the flight path.

Participants were also aware of the general inconsistencies in depicting the "top altitude" on departure charts (see Appendix F, ACF issue paper 13-01-266). Jeppesen and the FAA are both currently updating how these data are presented. The participants knew that the information was important and they want it to be easy to find.

Chart producers generally do not add their own notes to charts, but we did find a few. First, Jeppesen adds notes about direct distances between the runway end and first waypoint on a departure or last waypoint on an arrival (cf. EDETH and FRDMM in Appendix B.) Not all participants used the distances, but some found them helpful and looked for the information. The distances provide a sense of scale (or timing).

Jeppesen also added a speed note on BLZZR. This note was a bit confusing because it does not apply to all of the runways, just some of them. Participants who selected a runway for which the speed did not apply sometimes spent extra time determining that the note did not apply. Also, some participants missed this note even though it was visually highlighted because of its unusual location in the plan view instead of in the briefing strip.

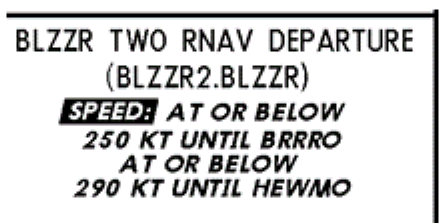


Figure 13. The visually highlighted speed restriction note only applies to RWY 22L/R and 15R. It does not apply to 4R, 9, 27, or 33.

4.4 Interactions with Air Traffic Control

In Section 4.2.1, participants mentioned interactions with ATC, and especially ATC interventions while flying an IFP, as being a common source of difficulties. This issue was also called out in the PARC/CAST report (FAA, 2013) in Finding 6, "Communication and Coordination between Pilots and Air Traffic Services." Some groups felt that this was the most common source of problems with flying an IFP. ATC interventions may be more difficult to handle if the airspace is "complex," such as the area around New York City and Washington, D.C. These areas are known for their high air traffic density and multiple airports in the region with crossing flight paths.

To look more broadly at interactions with ATC, we searched other sections of the summary files for feedback. We searched the files for terms such as "ATC" and "controller," and we looked at the following sections in the summary file:

- In-flight Techniques
    - Late Routing Changes
- General Comments/Questions
- General Procedure Comments
- Operational Use (at Specific Airports)

We gathered all the relevant observations into a table then grouped comments that were similar to each other, looking for themes in the feedback. Some of the themes we discovered matched well with the issues the participants brought up as factors in IFP difficulty, but other themes also emerged.

Participants mentioned several types of ATC interventions such as: late clearance amendments, runway changes, speed amendments, changes to a published speed or altitude constraint, unplanned vectors, holds, or just confusing instructions. Sometimes ATC requests interacted poorly with aircraft performance and participants had difficultly complying with the request in terms of getting the aircraft where ATC wanted. Participants were sometimes able to handle the ATC intervention by applying speed brakes or altering constraints within the FMS, but these strategies create workload (see Section 4.3.10.3).

4.4.1 Arrival Route and Landing Changes

Changing an arrival route can be a difficult, high workload task in flight. The amendment can create a change to both the lateral and vertical flight path and speed constraints also might change. This involves not only reprogramming the FMS but also updating the pilot's mental representation of the route. If there is plenty of time the workload is manageable, but under time pressure it may be easy to make mistakes. Important (but non-flight-critical) tasks such as *reviewing* the route (e.g., checking all the constraints) and *re-briefing* it with the other crewmember may be shed under time pressure.

Reprogramming the FMS and adjusting parameters in the MCP can require many steps, some of which are confusing, especially under time pressure. The crew has to call up the correct IFP with the correct transitions and configure the FMS so that the next waypoint that the aircraft will fly to is correctly programmed. Group 10 said they would also have to use software to re-compute landing distances if there were a runway change, and this can be time consuming. Another group (Group 7) pointed out that it can be particularly tricky to change the arrival from one with just a bottom altitude to an arrival with a "descend via" clearance (which has altitude constraints along the descent) because changing to a "descend via" clearance requires a shift in *mindset* as well as all the necessary FMS changes.

We heard different points of view on whether it was better to program the FMS early or later for arrivals and landing. If the arrival is specific to a runway, some groups preferred to set up the FMS early because there is more time for pilot review and briefing. However, programming the FMS later improves flexibility in case ATC changes the arrival and/or landing runway. At some airports (e.g., Denver, Las Vegas, and Los Angeles), participants said they receive frequent changes to the arrival; there can even be multiple sequential changes. At Los Angeles (LAX), Group 2 mentioned they have received as many as three different arrivals and three different runways on a single flight.

Participants reported that all the work that went into setting up an arrival and landing in the FMS might even be useless because they may be taken off the published route to do a visual approach or they may get vectors to an ILS approach. Another unfortunate consequence of switching the aircraft off the planned RNAV arrival or approach is that participants said they could not practice them under "easy" conditions, perhaps with less traffic or good weather in the area. Practicing an RNAV (RNP) approach under light workload conditions could build both controller and pilot confidence in the IFP so that they have more confidence when flying these under poor weather and/or higher workload conditions.

4.4.2 Speed, Altitude, and Lateral Changes during Descent

Controllers sometimes ask crews to comply with speed or altitude constraints different from those that are published on the IFP. Airline crews who fly the same routes become familiar with typical changes and will anticipate them. For example, participants who were familiar with the KORRY arrival into La Guardia, New York, mentioned that ATC often changed altitude constraints from the published "at or above" at RIDGY and SMYRNA to "at" altitudes at these points. Crews who are unfamiliar with the local ATC tendencies will be at a disadvantage when handling these interventions without advance notice.

Some participants mentioned that one problem with changing either speed or altitude constraints along a descent is that their careful VNAV planning during the review and briefing becomes useless; they are left making real-time adjustments ad hoc. (See Veillette (2016) to learn more about the planning that should go into a safe arrival and approach.) Another problem with ATC-issued speed amendments is that they add variability; controllers sometimes ask the crew to speed up and then suddenly ask the crew to slow down. Controller speed amendments can leave the aircraft in an awkward energy state (e.g., too high or too fast) for the next segment of the IFP.

Participants said they also have to adjust how they manage their aircraft and equipment to handle controller interventions. For example, some aircraft have a hard time slowing down while descending. Pilots of these aircraft want to be at lower altitudes earlier just in case they are slowed down. Sometimes, they will anticipate the need to be at a lower altitude by flying at the bottom altitude of window-altitude constraints on purpose. Controllers sometimes slow aircraft down on descent, which they might think is helpful because it would give the crew more time to reprogram the FMS, but in fact, slowing down on descent can make it harder for the plane to achieve the required descent rate.

Speed brakes can help pilots to manage controller speed adjustments, but the FMS "drag required" message is not always timely or accurate. Our participants said they use their judgement more than the message to determine whether and when they need to apply speed brakes (see Section 4.3.10.3).

The lateral path on descent could be altered without amending the arrival route. For example, there may be a deviation for weather or to enter a holding pattern. Although this may seem like a minor change, entering a holding pattern for air traffic management purposes can spike crew workload if the change is late, unexpected, or close to the airport (see Section 4.3.5).

4.4.3 Departure and Takeoff Changes

Departure and takeoff changes by ATC create similar issues for pilots as arrival and landing changes, especially if they are given at a late stage and create significant time pressure for crews. For example, crews still need time to reprogram the FMS, check the MCP, review the route, and re-brief the procedure. These tasks may have to be prioritized against many other tasks that the crews have to do to prepare for an on-time departure.

When crews are flying an "RNAV off the ground" procedure, it is especially important for them to check that the correct departure runway is entered in the FMS. Even a minor change such as a switch to a parallel runway requires reloading the FMS, checking the MCP, reviewing the route, and re-briefing the IFP because altitude or speed constraints might be different for the new runway. At Dallas-Fort Worth airport, ATC states the first fix on the departure as a strategy to remind pilots to check that the correct departure is loaded in the FMS.

Group 9 also pointed out that if ATC assigns a hard speed constraint on a departure, this can be a tripping point because pilots do not always know when to resume their normal speed. Published speed constraints on departures are accompanied by a "resume normal" note at the appropriate location, but with verbally issued speed constraints, there is ambiguity.

4.4.4 Working with ATC

Participants reported that they like to work *with* ATC. ATC can be helpful when they need to ask for relief from (speed or altitude) constraints or get general relief when they need time to understand something on the flight deck. Sometimes participants had trouble meeting co-located speed and altitude constraints on their aircraft and would ask controllers which of the two constraints they should meet. This can happen, for example, when there are off-nominal wind conditions for the IFP. Similarly, the aircraft may not be able to make an "at or above" altitude constraint on departure with a heavy takeoff weight or under hot weather conditions, and participants said they may seek relief from these constraints from ATC. ATC can respond to pilot requests for constraint relief by relaxing the constraint, assigning a new heading, or assigning a new IFP.

Participants also reported that ATC can also help pilots to clarify ambiguities or confusion with the IFP design. Most importantly, flight crews know they can rely on help from ATC with handling emergencies (e.g., asking for vectors, a safe altitude, or a switch to a simpler IFP). However, ATC is not always aware of flight crew tasks and workload or aircraft capabilities and flight characteristics.

4.4.5 Participant Perspectives on ATC and IFP Evolution

Our participants were keenly aware of the evolution of airspace designs and the roles of pilots and controllers. They perceive a shift in workload: increased workload for pilots and reduced workload for controllers. Some comments on this point include:

> *Reducing controller workload should not be a green light to increase pilot workload.* (Group 8)
>
> *These procedures have decreased the responsibility and accountability they [ATC] have over us. It should be a mutual responsibility.* (Group 8)
>
> *ATC is going from controlling to managing.* (Group 1)
>
> *I have friends who are controllers. They are less hands on. Just "follow the SID." All rote, that's how they are teaching the controllers. Less thinking. Controller knows he needs you at this altitude at this fix. Just saying descend via and climb via. I see this shift in workload. Not sure that is the right thing to do.* (Group 18)

Our participants were also aware of the huge transition within the controller population, as older controllers retire and younger ones come into the workforce. Group 18 felt that the newer controllers were unaware of flight deck tasks, timing, and workload. They have been in situations where the controller did not give the pilot enough time to prepare for an arrival (i.e., issued a very late clearance). They said that controllers assume the pilot is always set up and do not leave time for the pilot to sort out different information on the flight deck. Or, as mentioned in Section 4.4.2, the controller will ask the flight crew to slow the airplane down on descent, expecting that will help the pilots by giving them more time to reprogram the FMS. However, slowing down the aircraft actually makes descending quickly harder.

Participants also recognized that new IFPs come with a learning curve, both for controllers and for pilots. Everyone needs time to learn and to practice, especially since there are so many new IFPs. With the increasing number of runway-specific arrivals, pilots need more advance notice to set up the FMS. But, as one pilot in Group 2 pointed out, it is hard to get that practice time when operational efficiency takes priority: "I'm discouraged from asking for these [new IFPs] because I know I'm slowing them [ATC] up."

4.5 Flight Crew Factors

One of the operational complexity factors listed in Table 6 is the crew. An example of a crew-related operational complexity factor is their familiarity with different types of IFPs. Pilots can increase their familiarity with PBN IFPs through formal training, on-the-job training (in-flight experience), or self-training. They build upon their prior knowledge and experience. The end results should be that the pilot has an understanding of how to interpret and use an IFP, and has knowledge about techniques for handling different types of IFPs in their aircraft. This is a difficult task because new PBN IFPs are being implemented rapidly. So, pilots have to stay on top of a lot of changing information. As one participant in Group 17 said, "You never have enough knowledge." However, a participant in Group 12 reminded us that it is easy to blame pilots for making a mistake, but it is important to take a step back and see if the IFP is designed perfectly too.

Here we examine some of the challenges that pilots face in keeping their knowledge of PBN IFPs current. Section 4.5.1 considers some evolving PBN terminology. Section 4.5.2 considers participant feedback about their formal and informal training on PBN IFPs. In Section 4.5.3, we report on researcher observations about good practices that some flight crews demonstrated while reviewing and briefing the PBN IFPs in the study.

4.5.1 Knowledge and Use of PBN IFP Terms

One of the on-going challenges with PBN IFPs is that there are new terms that are not well established in their use and definition. We asked participants about some of these terms, particularly: "RNAV 1" (discussed in Section 4.5.1.1), and "climb via" and "descend via" (discussed in Section 4.5.1.2). We also listened carefully to the terms that participants used in their conversations with each other. We recorded some of the more interesting nonstandard terms because they might represent concepts that should be defined more formally. These are presented in Section 4.5.1.3.

4.5.1.1 RNAV 1

We asked participants to explain the term RNAV 1, which was in a note on the BLZZR SID. Just four groups understood that RNAV 1 referred to a requirement to stay within a 1-mile width for their lateral path (Groups 1, 9 13, 19). Nine groups had no significant understanding of the term RNAV 1 (Groups 2, 3, 4, 5, 6, 7, 14, 17, and 18). They admitted being unfamiliar with the term.

The remaining six groups (Groups 8, 10, 11, 12, 15, and 16) had varying degrees of partial knowledge. Some participants were not sure about the difference between RNAV 1 and RNAV (area navigation alone), with which they were familiar. Some thought that RNAV was a continuum of RNP, so that numbers less than 1 (such as 0.3 and 0.15) were RNP values while numbers 1 and greater than 1 referred to RNAV values. They were not aware of an important difference between RNAV and RNP, which is that RNP systems are required to self-monitor and alert the pilot if the performance is degraded beyond criteria. RNAV does not have a self-monitoring capability. Also, RNP and RNAV 1 are criteria that aircraft systems have to meet and the operator has to be approved to fly; these are not factors that the crew has any control over, the crew just has to be aware of whether they are authorized.

Groups who were qualified for RNP AR operations were generally more aware of the differences between RNP and RNAV 1. However, in general, the participants had not heard of the term "navigation specification" (often shortened to "navspec") which is the technical term for the performance requirement that aircraft systems have to meet to be authorized for particular performance-based operations. "RNAV 1" is an example of a navigation specification.

4.5.1.2 Climb Via and Descend Via

We did not directly ask participants about their knowledge of climb via and descend via clearances, so our information on these terms is limited. Participants sometimes brought up "climb via" in response to a question about a note on the EDETH SID, which labeled it a "stepped climb." This is a nonstandard note added by Jeppesen. The note has since been removed because its meaning was unclear to pilots. However, when asked to explain what it meant, most participants guessed that the note referred to the altitude constraints on EDETH, and that they could get a "climb via" clearance for the SID. About half of the groups recognized that "climb via" was a clearance, and not a type of IFP. A few of the participants said they had not flown a SID with a climb via clearance. In contrast, almost all participants clearly recognized the term "descend via" and had experience flying those clearances. Just one group called FRDMM a "descend via arrival" indicating that they might not realize that "descend via" is a clearance and not a type of IFP.

4.5.1.3 Nonstandard Terms

We noted examples of nonstandard terms used by participants because they could point out areas where standardization might be useful, especially if the nonstandard term is confusable with a concept that needs to be identified clearly. Nonstandard terms may also point out areas where training might be useful. However, nonstandard terms may not always be a problem. They could be deemed acceptable as long as the communication is successful within the crew.

Participants used nonstandard terms for different types of altitudes, such as the top and bottom altitudes on SIDs and STARs. When referring to the top altitude they sometimes used that term (top altitude), or they did not give it a name, or they called it the *maintain altitude* or *final altitude*. To refer to the bottom altitude, groups either used that term (bottom altitude), or they referred to the *minimum altitude* or *final altitude*.

For altitude changes on climb, some participants used the term *step altitude*, which, interestingly, does not imply whether they are going up or down. For changes in altitude on descent some participants used the term *step down,* regardless of whether the IFP was an arrival or approach. Group 7 called OPDs *step down arrivals*. IFP designers use the term *step down* only to refer to altitude changes that are necessary for obstacle clearance, which are typically only on approaches. So participants used the term *step down* differently from IFP designers.

Group 18 made a distinction between *obstacle SIDs* and *ATC SIDs. Obstacle SID* was their term for SIDs with physical constraints such as terrain or man-made obstacles. *ATC SID* was their term for SIDs with constraints created by ATC for traffic flow purposes. This same group also created their own abbreviation for "climb via" SIDs, *CVS*.

Finally, some groups used the terms *hold-down* or *ceiling* when referring to "at or below" altitude constraints. Group 1 used the term *bracket* to refer to window-altitude constraints. RF legs were sometimes called a*rc turns*.

4.5.2 Participant Feedback on Training for PBN IFPs

Near the end of the discussion, we asked participants for their thoughts on training as related to the task of flying IFPs. This was a relatively small topic in the test protocol, which did not examine training comprehensively. So, the feedback we obtained from participants was rather general. Some participants spoke about their current training programs and how they could be improved. For example, Groups 2 and 4 felt that some of their training did not apply to the operations they actually flew. Similarly, Group 18 mentioned they trained on stalls, but stalls are not the biggest risk. Groups 3 and 12 said that training was sometimes reactive to specific safety events.

Some participants gave general recommendations for improving pilot training, such as the need for flight crews to take ownership of their training (Group 18), and the need to raise the bar on pilot manual flying skills (Group 6). Group 4 suggested additional training on how to use the EFB chart software. Group 18 recommended that air traffic controllers should have more experience on the flight deck.

There were a few recommendations regarding training for PBN operations. Groups 2 and 17 said that RNP AR operations require regular specific training, and practice in line operations. Group 9 asked for more than an "information notice" (memo) on "climb via." Group 2 recalled that they did not get training for the Denver airspace redesign, just updates to their charts. Group 17 said they would like to practice the challenging IFPs in the simulator, not just the easy ones.

Group 7 and others asked for more training on the logic behind OPDs. They wanted to know/understand why IFPs are designed the way they are. They asked question such as:

- Why are there so many constraints?
- What's the purpose of a constraint? Can I get relief from ATC?
- Why are some irrelevant items highlighted (e.g., speed constraints that are not relevant) and important information (e.g., nonstandard constraints) not highlighted?

4.5.3 Flight Crew Good Practices

In observing participants, we noticed that some groups and individuals appeared to handle review and briefings especially well. We noticed three key areas where the best-prepared participants excelled: depth of information processing, flexibility of mental representation, and thoroughness of their process or technique.

Certain observable behaviors indicated a deeper level of information processing such as when participants clearly reviewed all the notes on an IFP, or did mental math to check the necessary vertical rates. When these participants spoke about how they handled flying the IFPs, they also demonstrated a deep knowledge of aircraft systems' logic and limitations, as opposed to describing the automated systems as "magic." These participants spoke about looking at raw data, not just the information as presented to them in the integrated flight deck displays. They were self-motivated learners who tried to understand why IFPs were designed the way they were. As a result, they tended to be more familiar with what to expect on different types of IFPs.

Participants who had flexible mental representations of the flight path were more aware of the spatial aspects of the flight path, not just its depiction on the chart. For example, they were aware of a "sharp turn" and the distances between waypoints. They were aware of the locations and distances along the IFP relative to familiar places, such as what US state they would be over. With a flexible representation, these participants easily moved between a spatial representation of the flight path (e.g., distance along the route), and a time-based representation, knowing how much time that segment would take to fly. These participants were very aware of time along the route. They were aware of whether an upcoming event would happen soon, or after some time. These participants also appeared to be more able to identify ambiguities in the IFP design, as if they could sense whether their mental representation was complete or not.

Some participants demonstrated a thorough process and flight technique. For example, they would consistently do individual reviews of the IFP before they began the briefing. Their briefings were consistent, thorough, and efficient. They used full sentences in their briefing, emphasizing important items through sentence construction and tone of voice. These were the participants who spoke consciously about their process and technique. It did not just happen; this was the result of thoughtful planning. They spoke of doing multiple briefings (initial and updates), and of taking their time to plan ahead. They also spoke about making a conscious transition between flying with automated systems and manual flying.

Although not every participant demonstrated the very best techniques described above, there were still many who demonstrated good habits to help them review, brief, and fly the IFPs. Some of the more common good habits were:

- Anticipating ATC interventions and planning for them, especially if the participants were in a familiar location
- Making an effort to practice flying manually
- Using standard/consistent terms within the crew
- Good communication practices (e.g., ask for questions at the end of a briefing)
- Knowing where to look when monitoring automated systems
- Thinking and planning ahead; knowing what to expect next.
- Using memory aids (e.g., taking notes, using a highlighter tool on the EFB, moving their finger along the route on the chart, using a physical motion of their hand to indicate an expected turn)
- Memorizing critical information (e.g., direction to turn for a missed approach)

5 Discussion

Now that we have gathered and analyzed participant input, we can understand the line pilot's view of IFP and chart complexity. In this section we address not just the observations and participant feedback, but our interpretation of these findings. Section 5.1 presents a framework for the different sources of subjective IFP and chart complexity. In Section 5.2, we present our thoughts on how participants used charts in this study. Section 5.3 presents some ideas for further research.

5.1 Subjective Complexity

We define a *subjective complexity factor* as one that requires an extra mental or physical step by the pilot. If participants mentioned that they would be especially aware under certain circumstances, or especially careful, these were our cues that there was subjective complexity.

Figure 14 summarizes the key findings from this study. The gears in the center of Figure 14 show the three types of subjective complexity factors and how they drive each other. The gear sizes vary to indicate the relative importance of each factor. Individual sources of subjective complexity are listed in each of the boxes next to a gear.

Operational complexity factors are shown in a cloud in the upper left corner. While operational complexity affects final implementation, it is not connected directly to the IFP and chart design. Operational complexity is discussed in Section 4.2.3. These are factors that affect daily operations, such as ATC interventions, aircraft factors such as the available automated systems and their ease of use, crew factors such as fatigue and familiarity with the airspace, operator factors such as ground support for route planning, and environmental factors such as traffic and weather.

Two crosscutting issues are listed in the box on the left of the diagram, visual density, and inconsistencies between different IFPs. The difficulties discussed in Section 4.3 illustrate each of the specific subjective complexity factors for line pilots.

In the sections below, we flesh out the interpretation of the factors illustrated in Figure 14. First we discuss the three main sources of subjective complexity (Section 5.1.1). Then we discuss the crosscutting factors (Section 5.1.2). Next we consider how different subjective complexity factors should be weighted (Section 5.1.3). Finally, we compare the new model of subjective complexity with the IFP designer view of IFP complexity presented earlier (Section 5.1.4).

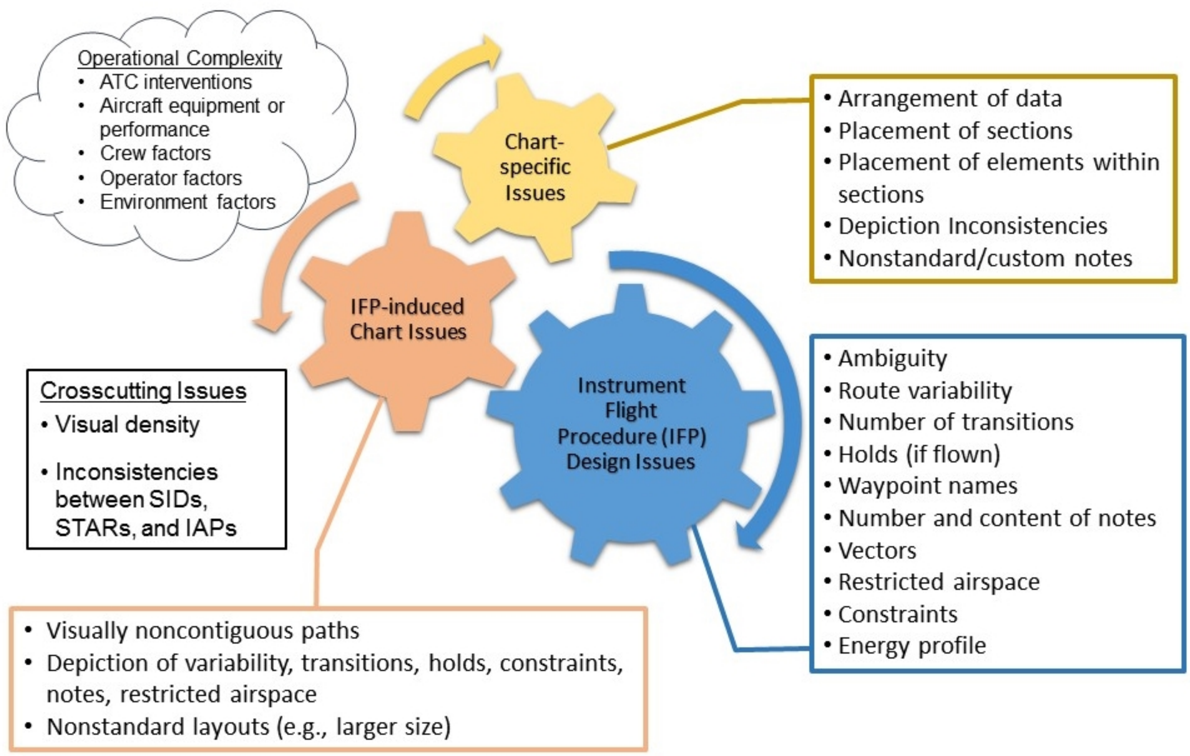


Figure 14. Line pilot subjective complexity framework.

5.1.1 IFP and Chart Sources of Subjective Complexity

IFP design parameters (e.g., energy profiles and constraints) are the primary source of subjective complexity, as indicated by the largest gear in Figure 14 (on the lower right). Other IFP design parameters shown here include route variability, number of transitions, holds (if flown), waypoint names, the number and content of notes, vectors, and restricted airspace. Ambiguity is also listed as an IFP design factor (see Section 4.3.1).

All of the IFP design parameters are provided to chart designers in the IFP specification (discussed in Appendix A). Chart designers have to deal with how to depict all the IFP elements, including the transitions, holds, constraints, notes, et cetera. IFPs that have more constraints, for example, will have more elements on the chart, increasing visual complexity. These issues are represented by the medium-sized gear in Figure 14 (on the left side).

When the chart designer is unable to draw the IFP flight path in a standard chart format, alternative formatting such as visually noncontiguous paths (including multiple-page formats) or larger page sizes for paper charts (e.g., trifolds and bi-folds) are considered. Another option is to use a variable scale for the plan view on an IAP if the IFP design is too long to fit in the standard scale.

Novel chart formats create situations where individual chart designers make one-off decisions about the placement of elements and arrangement of data (i.e., chart composition). There can be inconsistencies because of the novelty of the chart design. These inconsistencies and novel depiction formats can result in charts that pilots need to review more carefully.

Chart-specific composition issues are represented in Figure 14 by the smallest gear (at the top of the figure). These issues can be a secondary result of the IFP design (or might be unrelated to IFP design), but they too can create some confusion for pilots during the review and/or briefing.

5.1.2 Crosscutting Sources of Subjective Complexity

There are two issues that go beyond the IFP design and the chart design. First, if the airspace is dense (with a lot of aircraft traffic, many air routes, or both), that necessitates a complex IFP design, with corresponding visual complexity from the density of waypoints and flight paths. Second, there may be issues regarding the consistency between different types of IFPs (see Section 4.3.12). As the numbers of constraints and path segments increase on SIDs and STARs, there may be more parallels with IAPs, which may uncover latent discrepancies between these different IFPs.

5.1.3 Weighting of Subjective Complexity Factors

The different subjective complexity factors are not weighted equally. Some subjective complexity factors are easily addressed by flight crews while others create multiple workload penalties. We tried to understand the penalties by examining in more detail what were the extra steps, how often they occur, and whether they required more or less attention or time to manage. For example, managing constraints is a *process*, not a single step. Unlike using charts, handling constraints creates workload at several points in time. Chart visual complexity factors create less workload than IFP complexity factors because the chart is primarily referenced during the initial set up of the automated systems and crew briefing. By the time the crew is flying the IFP, they have answered questions they had about the chart. Also, factors that affect tasks done during low-workload situations (pre-flight or cruise) may be less critical than factors that affect tasks done in higher workload situations.

5.1.4 Comparison of Line Pilot and IFP Designer Perspectives

Table 1 in Section 2.3 described the IFP designer's view of complexity. Comparing the list of subjective complexity factors in Figure 14 with the complexity factors in Table 1 shows little overlap between these views of complexity. These two views produce different insights into what makes a IFP complex. Specifically:

- Table 1, constructed from the point of view of the IFP designer, breaks the path into vertical, lateral, and speed dimensions. But from the pilot's perspective, both the vertical and speed dimensions are wrapped up together in constraints.
- Other elements in Figure 14, such as waypoint names, content and number of notes, IFP variability, ambiguity, and even the energy profile are new factors not considered in Table 1.
- The subjective complexity framework provides a new way of thinking about how to improve the depiction of IFPs too.

- Another new concept in the subjective complexity framework is that operational complexity affects the IFP's use in the real world, but cannot be controlled by the IFP or chart designer.
- The subjective complexity framework also recognizes that complex airspace designs (with many air routes and/or significant aircraft traffic) are likely to increase both the number of IFPs, and the complexity of the IFPs in terms of numbers of constraints and waypoints, which will impact the visual density of the chart.

Another interesting observation about the subjective complexity framework is that participants did not mention lateral complexity as a difficulty. There are a number of possible explanations for this finding. It could be that automated systems for lateral navigation are so reliable that pilots can delegate that task effectively. It could also be that pilots can monitor lateral path relatively easily through charts and aircraft navigation displays. ATC also monitors the aircraft's lateral path, giving the pilot yet another way to identify and correct any lateral path deviations.

5.2 Using Charts

As we observed participants using the charts to review IFPs, we noticed that they varied in their speed, fluency, and comprehension.

Participants spent different amounts of time reviewing charts prior to the group review. There did not appear to be any pattern as to how much time they spent between operators, or groups. These appeared to be just individual differences.

There was also no clear relationship between the amount of time they spent reviewing the chart and the thoroughness of their review and/or verbal briefing. Sometimes, participants who spent more time on the briefing used that time on relatively minor details (e.g., how to pronounce a waypoint name) that did not improve the quality of the briefing. Other participants, who were quick to look over the chart, could easily answer detailed questions about its content.

Fluency of the briefing was evident in the speaker's delivery, specifically, his/her voice inflections, transitional sentences, cadence, and style. Fluent briefers chose their words carefully, speaking in short clear sentences, emphasizing key points through their voice. They indicated a mastery of the material, as though they had read ahead, and were just paraphrasing the most important points.

Some participants clearly had a plan for the review and briefing that they followed every time; individually, they were very consistent and knew what information was important to brief. Other participants seemed less consistent; sometimes they were more thorough than others.

We also observed that some participants were more comfortable than others in using the chart alone, without the FMS in front of them. It is not clear whether being able to use the chart alone is a skill that should be encouraged and trained, or if it is not critical and does not reflect any weaker understanding.

Similarly, some participants who worked for airlines with Dispatch units were comfortable relying on the dispatcher's analysis of climb performance. This could be a significant reduction in workload for the flight crew. Air Taxi and corporate operators did not enjoy this support, however, and tended to be more directly aware of aircraft performance issues.

We also noticed that flight crews who were familiar with each other (typically corporate crews) often communicated very smoothly and effectively about the IFP and chart. These groups also tended to be highly familiar with the specific aircraft they were flying and had deep knowledge and understanding of its systems.

Some operators had more clearly defined roles for the PF and PM than others. These roles might vary based on workload. Ultimately, however, both members of the flight crew should be proficient in how they review and brief the chart and IFP.

5.3 Areas for Research

There are many potential research questions that could be explored. Some of the questions are about current practices while others examine what might be best practices for the future. For example, we do not currently understand the ATC perspective on IFP designs and how well they work in practice. We do know that our participants said their job would be easier without ATC interventions. So it would be useful to understand why and when ATC does intervene and whether these interventions could be reduced. It would also be useful to know what controllers understand about aircraft capabilities, in general, but also specifically, for particular IFPs. We divided other areas for research into four categories, described below.

1) Best practice for chart design
    - Would a visual depiction of the vertical path for arrivals and departures be useful? Would such a depiction be feasible and valuable on a static depiction of an IFP?
    - How should data-driven terminal charts be designed to ensure good pilot reviews and full understanding of IFPs?
2) Best practice for IFP design process
    - How do we know that flight path constraints were minimized? Were alternate designs (with fewer constraints) tested?
    - Were charts prototyped to show whether the IFP can be clearly depicted in standard formats?
    - How can we use the subjective complexity framework during the IFP design process?
    - How do we balance additional needs for training with simplifying IFP design? Can the IFPs be designed more consistently to reduce the need for pilot training?
3) Best practice for pilot training
    - What training do line pilots currently receive, and could this be improved to make flying IFPs more consistent and reduce workload?
    - How much do we want to encourage/train/ask pilots to internalize the IFP? What is the right level of expectation?
    - How can we improve pilot reviews and briefings in a way that reflects performance of the best prepared flight crews?
4) More fundamental questions
    - Is the purpose of the chart to *verify* the procedure or to *comprehend* the procedure? Or to retain key information?
    - How does trust in automated systems affect pilot review of the IFP?
    - Can we measure the performance impacts of IFP complexity? How would that be useful?
    - Could performance data be used to prioritize subjective complexity factors?

6 Recommendations

Results of this study provide insights for all stakeholders in the process of IFP design, implementation, and use. Stakeholders will need to develop actions to address these recommendations cooperatively. Each of the recommendations below originates from a pilot need. There may be different ways of satisfying these pilot needs, so we do not attempt to provide prescriptive solutions.

Some of these recommendations, particularly those with charting implications, may need to be addressed by the government-industry Aeronautical Charting Forum (ACF). ACF issues papers related to our recommendations are summarized in Appendix F. These issues papers are referenced within each of our recommendations as appropriate. The full issues papers from the ACF can be found at https://www.faa.gov/air_traffic/flight_info/aeronav/acf/).

6.1 IFP Design Recommendations

These recommendations come directly from the list of subjective complexity factors that affect IFP design.

- Minimize flight path constraints.

  Constraints create pilot workload during reviews and briefings. They must be reviewed if the route is amended. Pilots have to actively manage and monitor constraints in flight. Workload of managing constraints can vary greatly depending on the aircraft automated systems and their ease of use.

- Minimize flight path transitions.

  Transitions add variability to the flight path, they add visual complexity to charts, and they add a decision point for pilots.

- Ensure that energy profiles are smooth between adjoining IFPs and/or segments of IFPs.

  Pilots manage and monitor aircraft energy as they climb and descend. The flight path should allow a smooth climb and descent, without sudden changes that surprise the pilot. IFP designs should consider that today's aircraft are aerodynamically cleaner than older aircraft, so they need more advance notice to slow down.

- Waypoint names should be pronounceable, short (with few syllables), and, ideally, familiar.

  Pilots review waypoints in their crew briefings, which are quick and focused. Awkward waypoint names take extra time and may create confusion. Waypoint names should be memorable to help pilots learn the airspace, but not at the expense of pronounceability and familiarity. Simple names will also aid pilots who are not native speakers of English.

- Minimize and prioritize notes.

  Be aware of the intended audience and write the note for that audience. Pilots learn to ignore notes if they do not apply.

6.2 Recommendations Related to Operational Complexity

These recommendations come from our findings related to operational complexity factors such as traffic, weather, pilot fatigue, or aircraft systems.

- IFP designers should assume that one or more operational complexity factors will affect normal operations.

The IFP should be designed to absorb normal operational variations. Designers should not assume best case conditions for normal operations. There should be some allowance in the IFP design for situations where the flight crew needs a little extra time to manage the flight and coordinate with ATC. IFPs that are designed with the assumption that all systems are functioning perfectly are brittle.

- IFP designers should be better informed about aircraft equipment variation and flight deck tasks and perspectives.

  Designers should understand how flight crews manage flight path constraints and air traffic interventions in particular. This will help them to understand the effects of IFP design on flight crew workload. Controllers also need this understanding so that they and the flight crews work together better to handle in-flight route and constraint amendments.

- The range within which runway changes are not allowed should be increased to reduce flight crew workload during arrivals, especially for arrivals into terminal areas with high traffic density or complex arrival routes.

  Currently, ATC is allowed to change the landing runway up to 10 miles from the runway transition point (FAA Order 7110.65W, 2015). This is sometimes insufficient time for pilots to reprogram the FMS, check the MCP, review, and re-brief the new path (see Section 4.4.1). Pilots may also need time to re-compute landing data for a different runway, even if changing to a parallel runway. All of these tasks are especially hard in busy airspace (e.g., La Guardia and Atlanta), which may be prone to landing runway changes. This topic is also addressed in the PARC/CAST report (2013). It has been actively debated because this issue directly trades off flexibility and complexity; allowing later runway changes increases flexibility for airspace operations, but increases complexity for flight crews.

6.3 Joint IFP Design and Chart Recommendations

- Develop guidance to decide when to separate flight paths into different IFPs or keep a single IFP.

  If many paths are on a single IFP, there should be additional design guidance on whether to split the depiction onto multiple chart pages (or electronic images). There are pros and cons for separating IFPs onto different images. Guidance should be developed so that there is a convention for making the decision, rather than to let each decision be made independently, without considering what has worked or not worked elsewhere. This guidance should be clearly communicated to flight crews and IFP designers so that they all know what to expect.

  We know from the results of Chandra and Grayhem (2013a and 2013b) that separating an IFP on to different pages can aid pilots in finding information more quickly if there are multiple paths (e.g., transitions or feeders) that are not always in use. For example, in the first version of the Boise RNAV (RNP) Z approaches, designers tried to combine features of both an arrival and an approach into a single IFP. This complex IFP was eventually split into simpler separate IFPs. The costs of adding chart images, even electronic ones, are not yet clear, however. Pilots must be able to quickly find the correct image out of a larger set of available images.

- Clarify and separate notes based on purpose.

  Determine whether the note is for action or awareness, and consider whether the two types could be separated for pilots. Notes for action are more important to flight crews than notes for awareness. All notes should also be written clearly (see Appendix F, ACF issue paper 16-02-328). If action is required, the action(s) to take should be evident. Also, notes should use language that is familiar to the intended audience. Notes for awareness, which may be routine and familiar to pilots, could potentially be moved to less used areas of the chart.

- Reduce the overall number of notes.

  Determine whether the chart is the best means for conveying specific notes or if another location or method of communication would be better. Determine whether some notes are no longer useful and remove these.

- Provide data on SIDs and STARs to give pilots a general sense of the terrain in the terminal area.

  Pilots could use these data to judge whether or not terrain will be a factor that they should plan for more carefully. Providing data directly for this purpose will discourage pilots from using potentially incorrect information from approach procedure minimum safe altitudes. A proposal on how to do this was recently submitted (see Appendix F, ACF issue paper 16-02-310). A previous paper submitted to the ACF addresses a similar concern from a different perspective (see Appendix F, ACF issue paper 11-02-244).

  In the study, some participants used data from the MSA for this purpose. However, the MSA is not always available on SIDs and STARs. In fact, MSAs are only valid for IAPs, but pilots may not be aware of the potential for incorrect data if they use the MSA for a SID or STAR. Participants in our study were interested to know whether there is high terrain within the terminal airspace (approximately 25-30 NM around the airport). They were also interested to know how busy they would be managing constraints as they got close to the airport and were at lower altitudes. The presence of high terrain in the area affects how participants said they would prepare to fly the procedure. Participants understood that SIDs and STARs are not drawn to scale, and did not ask for a to-scale representation of terrain, merely a general indicator.

6.4 Chart Recommendations

- Clearly indicate the “top altitude” on SIDs.

  Pilots know that this altitude is important for “climb via” clearances. They should not spend time hunting for it. Pilots need to enter this altitude into their autoflight system. Changes to the depiction of top altitude are in progress (see Appendix F, ACF issue paper 13-01-266).

- Carefully place notes.

  Consider grouping notes to make them easier to find.

- Have a clear graphical connection between sections if the flight path is split between chart sections (or pages/images).

  If the flight path is split and the graphical connections are not obvious, pilots may misunderstand the path or miss parts of it. Needing to understand how the different sections connect to each other increases the time to review it as well. Using text alone to connect noncontiguous path segments is not as helpful as having a clear graphical connection.

- Emphasize information that is nonstandard and of operational importance (e.g., nonstandard altitude and/or speed constraints).

  Pilots brief nonstandard aspects of the IFP so that they know what to expect.

6.5 Joint IFP Design and Training Recommendations

- Identify and eliminate ambiguity through training and clearer IFP design principles.

  Assume that not all pilots will have a detailed technical understanding of the IFP design or intention, or how it might unfold on their aircraft. For example, some pilots may not be able to predict in advance how their VNAV system will handle particular constraints.

- Improve pilot training and IFP design principles to improve pilot understanding on why IFPs are designed the way they are.

  This will improve pilot's ability to plan for different types of IFP, and will improve their resiliency to operational variations. For example, pilots would like to understand why there are so many constraints on some IFPs. They would like to know the purpose of the constraint and whether ATC could grant them relief or not from that constraint.

7 Summary

Our interviews and conversations with the participants were interesting and rich, covering a wide range of topics. Participants commented that they enjoyed providing feedback and learned from the study as well. They know that there will be significant changes to future operations and this was a chance for them to make sure the changes will be helpful and not disruptive.

We have made significant progress in understanding line pilot perspectives on the complexity of IFPs by analyzing what the participants said about IFPs, and by carefully observing how they briefed and reviewed IFPs. Our findings can be applied to any type of IFP, PBN or conventional. It appears, however, that more PBN IFPs use features (e.g., multiple transitions and altitude constraints) that are associated with complexity for line pilots.

One of the key contributions of this work was to define and separate different types of complexity. We now have a language for discussing different types of complexity that are often confused: operational complexity, IFP design complexity, chart complexity, subjective complexity, visual complexity, and objective complexity. We hope that stakeholders in IFP development will see the value of these distinctions in understanding how to simplify IFPs that are difficult to use in real operations. Identifying the type of complexity will help to identify which stakeholder(s) can address that issue.

A second key contribution was to identify a more comprehensive list of subjective complexity factors. The list of factors was longer than we anticipated. We went beyond the original goal of just gathering a list to developing a framework for subjective complexity. This framework is pilot-centered instead of designer-centered. It illustrates how different types of complexity are related and how they drive the final product, both the IFP and chart design. Our framework can help those involved in IFP design and implementation to anticipate how the IFP might be perceived and used by line pilots before flight operations begin.

A third key contribution was to identify operational complexity as a separate problem area. This issue cannot be addressed by IFP designers alone. To understand operational complexity further, we will need to understand variables that were out of scope for this study, such as pilot training, Air Traffic controller training, and Air Traffic priorities, requirements, and tradeoffs.

Another important product of this study is a better understanding of how pilots use charts during reviews and briefings. Pilots use charts for both tasks, but in different ways. This is the first study we know of that explicitly looked at how pilots use SID and STAR charts. Previous work focused on the design of IAP charts (e.g., Blomberg, Bishop, and Hamilton, 1995). Much of the critical work for understanding and flying the IFP is done during the IFP review and entry. Chart manufacturers may find this helpful for improving their designs, and for developing future data-driven chart products. We also observed that good IFP reviews go hand-in-hand with good briefings. Our findings may be useful for operators to consider in their pilot training.

We heard from pilot participants that they want to understand more about why IFPs are designed the way they are. Understanding the logic of IFP design may help them to review and fly the IFP better. For example, our participants wanted to know why there were so many constraints in some IFPs. They wanted to know the purpose of a constraint, and whether they could get relief from ATC by request. Finally they wanted to be sure that nonstandard constraints were salient. Interestingly, clarifying these points to pilots may also help IFP designers to be more consistent in their use of constraints.

We have taken the findings from this study and developed recommendations that may help ease operational implementation. These recommendations should be considered by all stakeholders cooperatively to develop solutions that will positively impact flight operations.

Finally, we have identified areas for future research. A key research issue is to understand the ATC perspective. We need to understand why and when ATC intervenes and whether these interventions could be reduced because they can create significant workload for flight crews.

Although we only interviewed 45 pilots, this study yielded findings that were corroborated anecdotally by many more pilots who have heard about its results in detail. As the findings become more widely known, we hope that the study will have far reaching effects towards improving PBN operations.

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Appendix A: IFP Source Data

Before considering how IFPs are depicted and used, it is helpful to understand their source data. The source data describes the IFP content in a detailed, prescribed format. The data and their format are explained in FAA documents (e.g., FAA Order 8260.19, *Flight Procedures and Airspace,* 14 July 2015). The 8260 series forms contain the official raw data for the IFP from the government. Chart producers use these data to create their depictions. Different forms are used for different types of IFPS. IAPs use form 8260-3, while SIDs use form 8260-15. The STARs tested in this study were created from a different form all together, the 7100-4. However, newer STARs will be created with 8260 forms similar to what is used for SIDs.

In this appendix, we first describe IFP source data at a conceptual level, then provide examples of source data. The first example is from a software tool called TARGETS (http://targets.cssiinc.com/). TARGETs is a software application that is used to design new SIDs and STARs. We also provide examples of the official government forms for IAPs and SIDs. We end with information on when and why IFP data, and associated charts, are updated.

Conceptual Description of IFP Source Data

An IFP is created from a set of inputs. These inputs include characteristics of the environment, such as obstacles, terrain, and restricted airspace that must be avoided.

Each IFP has entry and exit conditions. For example, a runway transition is the first component of a SID and the last component of a STAR (unless the IFP specifies vectors from ATC for these segments). The runway transition for a SID describes how to fly from the end of the runway to the initial fix defined for the route. For example, the aircraft might need to fly along the runway heading until reaching a specific altitude, then turn direct to the first fix on the route. For a STAR, the runway transition should join smoothly (both laterally and vertically) with the initial segment of the approach, unless vectors are required, in which case ATC is responsible for getting the aircraft smoothly from the end of the STAR to the beginning of the IAP.

A complete IFP design has the following elements:

1) Route Definition

   - Course (e.g., a list of defined leg types, such as “radius-to-fix” (RF), “direct to a fix” (DF), “course to a fix” (CF), or “heading to an altitude” (VA))
   - Transitions
   - Waypoint names
   - Climb gradient
   - Altitude constraints
   - Speed constraints
   - Holding patterns where needed[1]

[1] Holding patterns protect the aircraft from obstacles and other traffic. They are composed of a holding waypoint (which the aircraft must fly over), a heading along which to hold, outbound leg distance or time, and maximum speed. Holding patterns have maximum speeds to limit the turn radius for terrain avoidance. On arrivals, holds can help to absorb a delay due to weather or traffic. They may be relatively

- Contingency notes related to the route of flight (e.g., holding pattern speed)
- Minimum altitudes along the route

2) Equipment Requirements

   - Notes (e.g., “RNAV 1”)

3) Landing Minima Notes for IAPs

   - Contingency notes related to the landing minima (e.g., “RVR 18 with Flight Director or Autopilot or head-up display to decision altitude”)

Keep in mind, however, that SIDs and STARs are different from IAPs because IAPs are regulations (which must always be adhered to) and SIDs/STARS are not. SIDs and STARs allow controllers to issue one instruction instead of many, to explain how to fly into and out of the terminal airport environment. They are designed primarily to improve traffic flow in the airspace design, although obstruction clearances are met as well, of course. Charts for SIDs and STARs aid pilots by providing a graphical depiction of the cleared route. The graphic is usually accompanied by a text description that describes the initial routing. Charting standards for departures and arrivals are more flexible than standards for charting IAPs.

TARGETS Version of IFP Description

Figure 15 shows sample output from TARGETS. The output it produces is similar to the data in the FMS navigation database. Figure 15 shows just a small portion of data for a single IFP, which happens to be the MINNE ONE, a former departure out of Portland, Oregon.

This format is not familiar to line pilots. The table has technical acronyms and data. For example, the first column contains the ARINC leg types, coded with two letters.

FAA Criteria Check Results - RY10L to CROWN:HISKU

Leg Type	Waypoint	Turn Type	Alt Restr	Spd Restr	Turn Angle at Wpt	Turn Angle Status	DTA1	DTA1 Turn Rad	DTA1 Turn Alt	DTA1 Turn Spd	DTA2	DTA2 Turn Rad	DTA2 Turn Alt	DTA2 Turn Spd	Min Seg Length	Dist(nm)	Min Seg Status	Seg Comments	Climb Status	Climb Comment
VA		NONE	540		24.77	--					0.000				0.0	1.60	Pass		Pass	320 ft/nm
DF	RIVRR	FLY_BY			10.21	Pass	0.000				0.375				0.4	2.63	Pass		Pass	242 ft/nm
TF	WP12	FLY_BY			70.17	Pass	0.375				2.950				3.4	6.43	Pass		Pass	242 ft/nm
TF	WP15	FLY_BY	-9000		75.37	Pass	2.950				3.244				6.2	6.51	Pass		Pass	242 ft/nm
TF	MINNE	FLY_BY			74.71	Pass	3.244				5.878				9.2	32.43	Pass		Pass	242 ft/nm
TF	HISKU	FLY_BY	+2300 0		--	--	5.878								5.9	44.92	Pass		Pass	242 ft/nm

FAA Criteria Check Results - RY10L to CROWN:EASON

Leg Type	Waypoint	Turn Type	Alt Restr	Spd Restr	Turn Angle at Wpt	Turn Angle Status	DTA1	DTA1 Turn Rad	DTA1 Turn Alt	DTA1 Turn Spd	DTA2	DTA2 Turn Rad	DTA2 Turn Alt	DTA2 Turn Spd	Min Seg Length	Dist(nm)	Min Seg Status	Seg Comments	Climb Status	Climb Comment
VA		NONE	540		24.77	--					0.000				0.0	1.60	Pass		Pass	320 ft/nm
DF	RIVRR	FLY_BY			10.21	Pass	0.000				0.375				0.4	2.63	Pass		Pass	238 ft/nm
TF	WP12	FLY_BY			70.17	Pass	0.375				2.950				3.4	6.43	Pass		Pass	238 ft/nm
TF	WP15	FLY_BY	-9000		75.37	Pass	2.950				3.244				6.2	6.51	Pass		Pass	238 ft/nm
TF	MINNE	FLY_BY			54.00	Pass	3.244				3.924				7.2	32.43	Pass		Pass	238 ft/nm
TF	EASON	FLY_BY	+2300 0		--	--	3.924								4.0	46.56	Pass		Pass	238 ft/nm

Figure 15. Excerpt from an IFP specification.

close to the end of the common route. Holding patterns for missed approaches give aircraft a place to wait while awaiting further instructions from ATC.

IAP Example

The 8260-3 form provides the source data for IAPs. This information includes:

- Terminal routes with course, distance, and altitude
- Procedure turn and hold-in-lieu data
- Minimum altitudes and speed restrictions
- Missed approach instructions
- Notes for the pilot
- IAP amendment number

Figure 16 and Figure 17 below show the first two pages of the 8260-3 form for the Boise RNAV (RNP) Z to Runway 28L from September 2014. When the IFP is particularly complicated, some fields (such as the "Additional Flight Data" or "Note") require additional pages. In this example, the terminal routes that began on the first page continue in the second page, as do the notes. Figure 18 shows the FAA version of the IAP described in the source data in Figure 16 and Figure 17.

57 RNAV (RNP) Z RWY 28L TL 14-19

US DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

RNAV (RNP) - STANDARD,
INSTRUMENT APPROACH PROCEDURE,
TITLE 14 CFR PART 97.33

Bearings, headings, courses, and radials are magnetic. Elevations and altitudes are in feet, MSL, except HAT, HAA, TCH, and RA. Altitudes are minimum altitudes unless otherwise indicated. Ceilings are in feet above airport elevation. Distances are in nautical miles unless otherwise indicated, except visibilities which are in statute miles or in feet RVR.

TERMINAL ROUTES

FROM	TO	COURSE AND DISTANCE	ALTITUDE
CELOR (IAF)	OFTER (TF) (FB) (RNP 1.00)	299.98 / 7.24	6800
LIITL (IAF)	NEWKU (TF) (FB) (RNP 1.00)	260.75 / 3.13	8500
NEWKU	ROKTY (TF) (FB) (RNP 1.00)	259.61 / 4.00	8000
ROKTY	OFTER (TF) (FB) (RNP 1.00)	259.55 / 4.00	6800
DIKAC (IF)	CIPSA (TF) (FB) (RNP 1.00)	003.58 / 3.72	5000
(SEE FORM 8260-10)			

MISSED APPROACH

RNP: DA

CLIMB TO 6000 ON TRACK 280.13 TO JIMMI AND HOLD, CONTINUE CLIMB-IN-HOLD TO 6000.

ADDITIONAL FLIGHT DATA:
HOLD W, RT, 099.97 INBOUND.
DISTANCE TO THLD FROM 418 HAT: 1.16 NM.
ROUTE TYPE: A, H
ROUTE TYPE QUALIFIER 1: F
ROUTE TYPE QUALIFIER 2: S
CHART MANDATORY 6000 AT DIKAC.
CHART MANDATORY 7000 AT EKEME.
#TCH 2908.1 MSL (DO NOT CHART)
CHART MINIMUM 8000 AT CELOR.
CHART MINIMUM 9000 AT LIITL.

1. PT ___ SIDE OF COURSE ___ OUTBOUND ___ FT WITHIN ___ MILES OF ___ (IAF)
2. PROFILE STARTS AT HOBSI
3. FAC: 280.19 FAF: ___ DIST FAF TO MAP: ___ THLD: ___
4. MIN. ALT: HOBSI 3900
5. DIST TO THLD FROM OM: 3.11 MM: ___ IM: ___ 150 HAT: ___ 100 HAT: ___ GS ANT: ___
6. MIN GS INCPT: 3900 GS ALT AT: HOBSI 3900 OM: ___ MM: ___ IM: ___
7. GS ANGLE: 3.00 TCH: 50.0# 34:1 IS CLEAR
8. MSA FROM: RW28L 9400

MAG VAR: 15E EPOCH YEAR: 2005

MINIMUMS

TAKEOFF: SEE FAA FORM 8260-15A FOR THIS AIRPORT — ALTERNATE: N A — STANDARD

CATEGORY	A			B			C			D			E		
	DH/MDA	VIS	HAT/HAA	DH/MDA	VIS	HAT/HAA	DH/MDA	VIS	HAT/HAA	DH/MDA	VIS	HAT/HAA	DH/MDA	VIS	HAT/HAA
AUTHORIZATION REQUIRED															
RNP 0.15 DA	3276	4700	418	3276	4700	418	3276	4700	418	3276	4700	418			
RNP 0.30 DA	3346	6000	488	3346	6000	488	3346	6000	488	3346	6000	488			

NOTES:
CHART NOTE: FOR UNCOMPENSATED BARO-VNAV SYSTEMS, PROCEDURE NA BELOW -14C (7F) OR ABOVE 53C (128F).
CHART NOTE: FOR INOPERATIVE MALSR, INCREASE RNP 0.15 ALL CATS VISIBILITY TO 1 3/8, AND RNP 0.30 ALL CATS VISIBILITY TO 1 5/8.
CHART NOTE: GPS REQUIRED.
(SEE FORM 8260-10)

CITY AND STATE	ELEVATION / AIRPORT NAME	FACILITY IDENTIFIER	PROCEDURE NO./AMDT NO./EFFECTIVE DATE	
BOISE, ID	ELEVATION: 2871 TDZE: 2858 AIRPORT NAME: BOISE AIR TERMINAL/GOWEN FLD	RNAV	RNAV (RNP) Z RWY 28L, AMDT 1 18 SEPTEMBER 2014	SUP: AMDT: ORIG-B DATED 11/17/2011

FAA FORM 8260 - 3 / April 2006 (computer generated) PAGE 1 OF 6 PAGES

Figure 16. First page of Form 8260-3 for Boise RNAV (RNP) Z 28L, amended 18 September 2014.

US DEPARTMENT OF TRANSPORTATION - FEDERAL AVIATION ADMINISTRATION
RNAV (RNP) - STANDARD,
INSTRUMENT APPROACH PROCEDURE, - TITLE 14 CFR PART 97.33

Bearings, headings, courses, and radials are magnetic. Elevations and altitudes are in feet, MSL, except HAT, HAA, TCH, and RA. Altitudes are minimum altitudes unless otherwise indicated. Ceilings are in feet above airport elevation. Distances are in nautical miles unless otherwise indicated, except visibilities which are in statute miles or in feet RVR.

TERMINAL ROUTES, (CONT.):

FROM	TO	COURSE AND DISTANCE	ALTITUDE
EKEME (IF)	ELUMY (TF) (FB) (RNP 1.00)	100.09 / 3.80	6000
ELUMY	CIPSA (RF) (FB) (RNP 1.00)	(2.39 NM RADIUS CCW (CFFMS)/4.03	5000
CIPSA	ZOVAM (RF) (FB) (RNP 0.50)	(2.39 NM RADIUS CCW (CFFMS)/2.14	4300
ZOVAM	HOBSI (RF) (FB) (RNP 0.30)	(2.39 NM RADIUS CCW (CFFMS)/1.33	3900
OFTER (IF)	MUFPI (TF) (FB) (RNP 0.50)	280.34 / 4.00	5600
MUFPI	JUBEN (TF) (FB) (RNP 0.50)	280.29 / 2.05	5100
JUBEN	SAKVY (TF) (FB) (RNP 0.50)	280.26 / 1.45	4600
SAKVY	CEPAV (TF) (FB) (RNP 0.50)	280.23 / 1.20	4300
CEPAV	HOBSI (TF) (FB) (RNP 0.50)	275.80 / 1.49	3900
HOBSI (FAF)	RW28L (MAP) (TF) (FO)	280.19 / 3.11	
RW28L (MAP)	JIMMI (TF) (FO) (RNP 1.00)	280.13 / 11.15	6000

NOTES, (CONT.):
CHART PLANVIEW NOTE AT DIKAC (IF) : MAX 210 KIAS.
CHART PLANVIEW NOTE AT EKEME (IF) : MAX 210 KIAS.
CHART PLANVIEW NOTE AT CIPSA : MAX 180 KIAS.
CHART PLANVIEW NOTE ADJACENT TO DIKAC (IF): RF REQUIRED.
CHART PLANVIEW NOTE ADJACENT TO EKEME (IF): RF REQUIRED.
CHART PLANVIEW NOTE AT CELOR (IAF): (RNP 0.50).
CHART PLANVIEW NOTE AT LIITL (IAF): (RNP 0.50).
CHART PLANVIEW NOTE AT DIKAC (IF): (RNP 0.30).
CHART PLANVIEW NOTE AT EKEME (IF): (RNP 0.30).
CHART PROFILE NOTE: SEE PLANVIEW FOR MULTIPLE IF LOCATIONS.

QUALITY 7 CHECKED

CITY AND STATE	ELEVATION: 2871 TDZE: 2858	FACILITY IDENTIFIER:	PROCEDURE NO./ AMDT NO./EFFECTIVE DATE:	SUP:
BOISE, ID	AIRPORT NAME: BOISE AIR TERMINAL/GOWEN FLD	RNAV	RNAV (RNP) Z RWY 28L, AMDT 1 18 SEPTEMBER 2014	AMDT: ORIG-B DATED: 11/17/2011

FAA FORM 8260-10 / April 2006 (Computer Generated)

PAGE 2 OF 6 PAGES

Figure 17. Second page of Form 8260-3 for Boise RNAV (RNP) Z 28L, amended 18 September 2014.

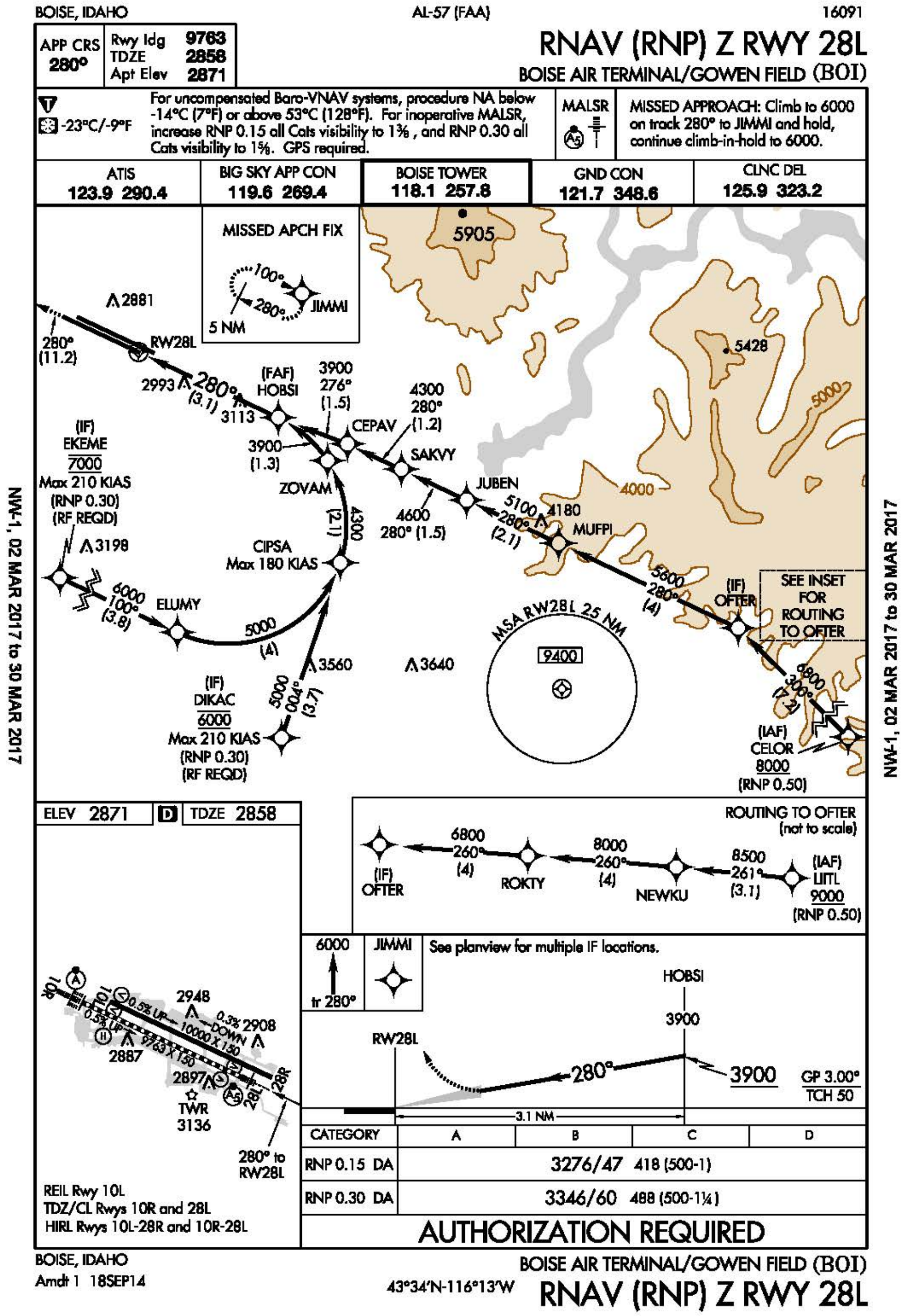


Figure 18. FAA depiction of the IFP specification shown in Figures 16 and 17.

SID Example

The 8260-15B form provides data needed to code SIDs:

- Runway transitions with course, altitude and speed restrictions
- Common route transitions with course, altitude and speed restrictions
- Enroute transitions with course, distance and altitude restrictions
- Notes for the pilot and takeoff minimums. (Notice that the wording of the note is specified in the form and used as such by the chart producer.)
- Which airports use the SID
- SID amendment number

Figure 19 and Figure 20 show the first two pages of the 8260-15B form for the EDETH TWO SID tested in this study. The chart for this source data is shown in Appendix B.

NFDD No. 091 05/12/2014 20

SL365

U.S. DEPARTMENT of TRANSPORTATION – FEDERAL AVIATION ADMINISTRATION

GRAPHIC DEPARTURE PROCEDURE (DP)

Bearings, headings, courses, tracks, and radials are magnetic. Elevation and altitudes are in feet MSL. Altitudes are minimum altitudes unless otherwise indicated. Ceilings are in feet above airport elevation. Distances are in nautical miles. Visibilities are in statue miles or feet RVR unless otherwise indicated. Graphic depictions attached.

DP Name	Number	DP Computer Code	Superseded Number	Dated	Effective Date
EDETH	TWO	EDETH2.EDETH	ONE	12/20/07	24 JUL 2014

TYPE: RNAV SID

DP ROUTE DESCRIPTION:

TAKEOFF RWY 34R: CLIMB HEADING 340.96 TO 4727, THEN LEFT TURN DIRECT SAPEE, THEN VIA DEPICTED ROUTE TO EDETH, THENCE ...
TAKEOFF RWY 34L: CLIMB HEADING 340.95 TO 4727, THEN LEFT TURN DIRECT SAPEE, THEN VIA DEPICTED ROUT TO EDETH, THENCE...
TAKEOFF RWY 35: CLIMB HEADING 345.99 TO 4727, THEN LEFT TURN DIRECT SAPEE, THEN VIA DEPICTED ROUT TO EDETH, THENCE...
...VIA (TRANSITION) MAINTAIN FL230 OR LOWER FILED ALTITUDE. EXPECT FILED ALTITUDE 10 MINUTES AFTER DEPARTURE.

TRANSITION ROUTES (GRAPHIC DEPICTION ONLY):

Transition Name	Transition Computer Codes	From FIX/NAVAID	To FIX/NAVAID	Course	Distance	MEA	MOCA	Crossing Altitudes/Fixes
MILFORD	EDETH2.MLF	EDETH	SEVYR	172.61	27.92	13000	8100	
		SEVYR	MLF VORTAC	172.56	51.71	FL220	9500	
BRYCE CANYON	EDETH2.BCE	EDETH	SEVYR	172.61	27.92	13000	8100	
		SEVYR	MLF VORTAC	172.56	51.71	FL220	9500	
		MLF VORTAC	BCE VORTAC	125.88	52.43	FL240	12400	
BERYL	EDETH2.BERYL	EDETH	TRANT	180.35	29.86	13000	8600	
		TRANT	BERYL	180.00	80.10	FL220	11400	
COALDALE	EDETH2.OAL	EDETH	TRANT	180.35	29.86	13000	8600	
		TRANT	OAL VORTAC	239.89	236.49	FL220	14400	

PROCEDURAL DATA NOTES/TAKEOFF MINIMUMS:

TAKEOFF MINIMUMS
RWY 34R, STANDARD WITH A MINIMUM CLIMB OF 420 FT PER NM TO 10900.
RWY 34L, STANDARD WITH A MINIMUM CLIMB OF 430 FT PER NM TO 10700.
RWY 35, STANDARD WITH A MINIMUM CLIMB OF 425 FT PER NM TO 10800.

QUALITY 2 CHECKED

FAA Form 8260-15B / August 2009 (Computer Generated) Page 1 of 3

Figure 19. First page of Form 8260-15B for the EDETH TWO SID.

NFDD No. 091 05/12/2014 21

U.S. DEPARTMENT of TRANSPORTATION – FEDERAL AVIATION ADMINISTRATION

GRAPHIC DEPARTURE PROCEDURE (DP)

Bearings, headings, courses, tracks, and radials are magnetic. Elevation and altitudes are in feet MSL. Altitudes are minimum altitudes unless otherwise indicated. Ceilings are in feet above airport elevation. Distances are in nautical miles. Visibilities are in statue miles or feet RVR unless otherwise indicated. Graphic depictions attached.

DP Name	Number	DP Computer Code	Superseded Number	Dated	Effective Date
EDETH	TWO	EDETH2.EDETH	ONE	12/20/07	24 JUL 2014

NOTE: RNAV 1.
NOTE: DME/DME/IRU OR GPS REQUIRED.
NOTE: RADAR REQUIRED.
NOTE: TURBOJET AIRCRAFT ONLY.
NOTE: FOR NON-GPS EQUIPPED AIRCRAFT: FFU AND DTA DMES MUST BE OPERATIONAL FOR BRYCE CANYON, MILFORD, AND BERYL TRANSITIONS. FFU, DTA, ILC, TPH, MVA, AND OAL DMES MUST BE OPERATIONAL FOR COALDALE TRANSITION.

TAKEOFF OBSTACLES NOTES:

NOTE: RWY 34R, POST 13' FROM DER, 349' RIGHT OF CENTERLINE, 3' AGL/4227'MSL.
NOTE: RWY 35, POST 55' FROM DER, 249' LEFT OF CENTERLINE, 2' AGL/4220' MSL.

CONTROLLING OBSTACLES:

RWY 34R, 34L, 35: 9,321' MSL TOWERS 403935.00N/1121207.50W

LOST COMMUNICATIONS PROCEDURES:

CONTINUE ON SID. COMPLY WITH PUBLISHED ALTITUDE RESTRICTIONS

ADDITIONAL FLIGHT DATA:

REFERENCE MAG VAR: KSLC 14E EPOCH YEAR: 95.
DME/DME/IRU ASSESSMENT: SAT (RNP 2.0)
AT BUCCO CHART: AT OR BELOW 10000, AT 230 KIAS.
AT SCANT CHART: AT OR ABOVE 10000.
AT HIDUT CHART: AT 11000.
AT TOOLE CHART: AT OR ABOVE 13000.
AT MUSAW CHART: AT OR BELOW FL230, AT 250 KIAS. RESUME NORMAL SPEED AFTER MUSAW.

AIRPORTS SERVED:

SALT LAKE CITY INTL SALT LAKE CITY, UT

COMMUNICATIONS:

ATIS, CLNC DEL, GRND CON, TOWER, DEP CON, 128.1, 307.05

FIXES AND/OR NAVAIDS:

FAA Form 8260-15B / August 2009 (Computer Generated) Page 2 of 3

Figure 20. Second page of Form 8260-15B for the EDETH TWO SID.

STAR Source Data

The 7100-4 form was used for the source data of the STARS tested in this study. The data for SIDs and STARs are similar. These include:

- Enroute transitions with course, distance and altitudes
- Common route transitions with course, distance, altitudes and speed restrictions
- Runway transitions with course, distance, altitudes and speed restrictions
- Notes for the pilot
- Determination if holds are established at certain waypoints used on the STAR
- Which airports use the STAR
- STAR amendment number

IFP and Chart Updates

After an IFP and chart have been developed, they are subject to revisions and updates. The revisions could be due to changes in the IFP design (e.g., flight tracks, altitudes, etc.), due to changes in other information shown on the chart (e.g., Air Traffic communication frequencies, runway data, or navigation equipment names and identifiers), or just due to findings from periodic design reviews. These latter types of changes can occur at any time, independent of IFP design changes. There is no single source of data for all the elements on a chart; the chart producer has to gather the data from different materials to update the chart, and each type of data may have its own date of effectiveness or implementation.

The FAA assigns an IFP "Amendment Number" to each standard IAP and subsequent modification. This number is shown on the chart to help the pilot check that the correct (latest) version of the IAP is used and to check that the data from the paper chart data matches the data for the IFP in the navigation database. When SIDs and STARs change, their number is revised upwards, so the change is relatively prominent to the pilot. For example, FRDMM TWO is the revised version of the outdated FRDMM ONE STAR.

Updated static charts are released to pilots on a standard 28-day cycle. However, only a small number of existing charts may change on any given update cycle. To update every one of the thousands of IFPs and charts in the United States can take months, or years, if there is a general change in the data or format.

Data in the navigation database can also change at different times. The navigation database is also updated on a 28-day cycle, but this can be off from the chart update cycle.

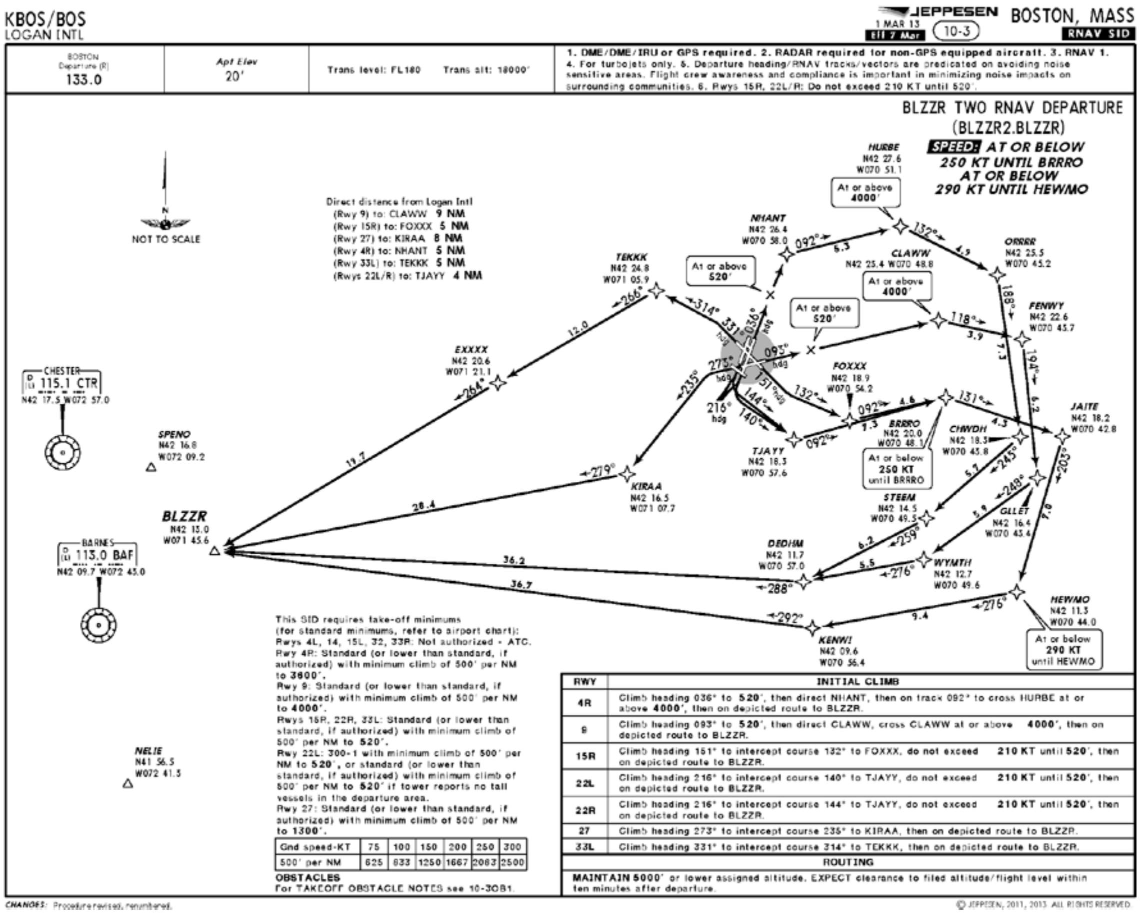
In the future, with electronic data-driven aeronautical charts, it will be possible to update data elements more frequently than conventional pre-composed charts in printed form are updated. Additionally, different data elements could potentially be updated at different intervals, based upon the origin and effectivity (currency) of the different data elements. However, updates to data elements will still be dependent on their origin and may have different effective dates, making it potentially more difficult for the pilot to verify the currency of every type of data.

Appendix B: Charts Images and Questions

BLZZR TWO RNAV

RNAV departure with multiple crossing runway transitions and no common segment.

1. What does RNAV1 mean?
2. Did you notice the speed constraints at BRRRO (250 kts) and HEWMO (290 kts)?
3. The runway transitions cross one another. Would these be confusing to fly?
4. Is it hard to read information for the crossing transitions?
5. There are segments off the runway that have a heading change that occurs upon reaching an altitude. Have you seen these before?
6. Speed constraints for specific runways are listed in the notes at the top and in the description of the Initial Climb. Which location do you prefer?
7. Did you notice the note about noise impact? Where else might you find this information?
8. A note says that Takeoff Obstacles are available on a separate page (10-30B1). Would you retrieve the other page to look at the obstacles?
9. What autopilot roll mode would you use for the initial departure segment off of 4R or 9 (HDG or LNAV)?
10. How would you monitor your cross track error on RNAV departures with an initial segment defined by a heading?



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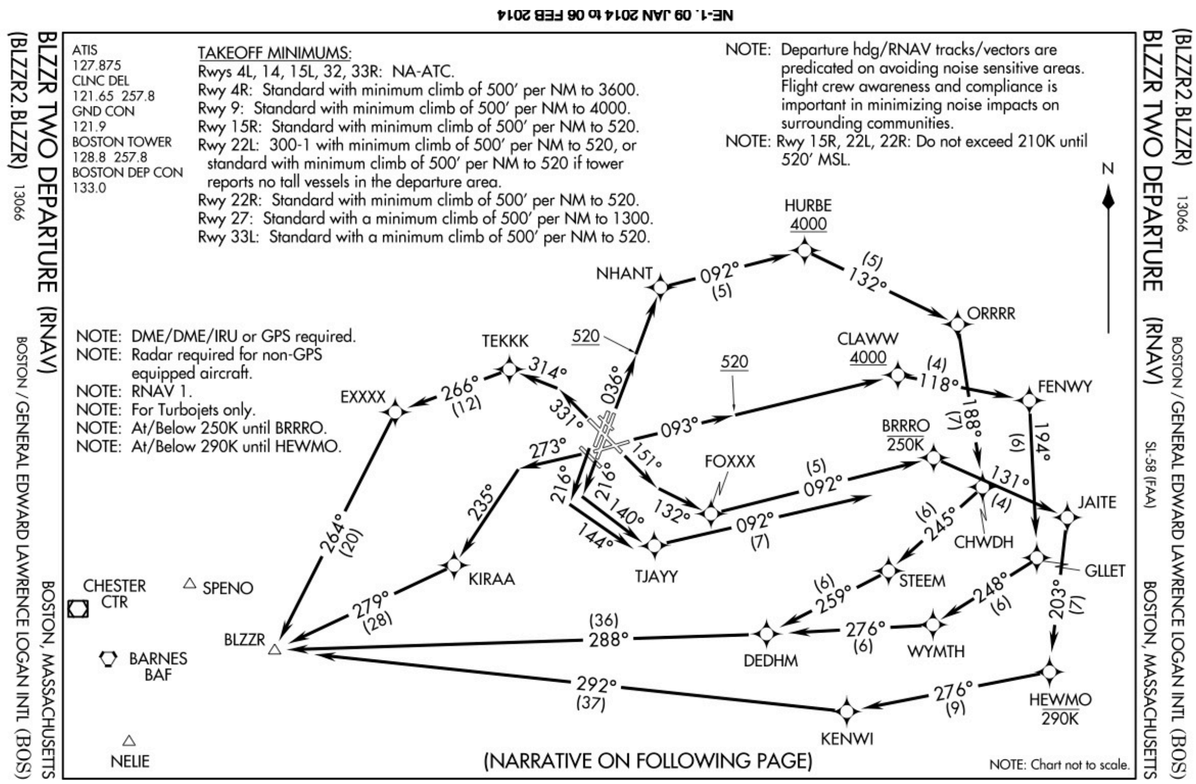


NE-1, 09 JAN 2014 to 06 FEB 2014

(BLZZR2.BLZZR) 13066 BOSTON / GENERAL EDWARD LAWRENCE LOGAN INTL (BOS)

BLZZR TWO DEPARTURE (RNAV) SL-58 (FAA) BOSTON, MASSACHUSETTS

NE-1, 09 JAN 2014 to 06 FEB 2014

▼ DEPARTURE ROUTE DESCRIPTION

TAKEOFF RWY 4R: Climb heading 036° to 520, then direct NHANT, then on track 092° to cross HURBE at or above 4000, thence. . . .
TAKEOFF RWY 9: Climb heading 093° to 520, then direct CLAWW, cross CLAWW at or above 4000, thence. . . .
TAKEOFF RWY 15R: Climb heading 151° to intercept course 132° to FOXXX, do not exceed 210K until 520 MSL, thence. . . .
TAKEOFF RWY 22L: Climb heading 216° to intercept course 140° to TJAYY, do not exceed 210K until 520 MSL, thence. . . .
TAKEOFF RUNWAY 22R: Climb heading 216° to intercept course 144° to TJAYY, do not exceed 210K until 520 MSL, thence. . . .
TAKEOFF RUNWAY 27: Climb heading 273° to intercept course 235° to KIRAA, thence. . . .
TAKEOFF RUNWAY 33L: Climb heading 331° to intercept course 314° to TEKKK, thence. . . .

. . . . on depicted route to BLZZR. Maintain 5000 or lower assigned altitude. Expect clearance to filed altitude/flight level within ten (10) minutes after departure.

TAKEOFF OBSTACLES:

Rwy 4R: Ships beginning 579′ from DER, on centerline, up to 50′ AGL/50′ MSL. Pole and trees beginning 1806′ from DER, 403′ left of centerline, up to 51′ AGL/79′ MSL.
Rwy 9: Ships 762′ from DER, on centerline, up to 65′ AGL/65′ MSL. Tank 5904′ from DER, 1453′ left of centerline, 109′ AGL/206′ MSL
Rwy 15R: Sign 45′ from DER, 267′ right of centerline, 6′ AGL/16′ MSL.
Rwy 22L: Pole 394′ from DER, on centerline, 15′ AGL/31′ MSL. Tower 3585′ from DER, 926′ left of centerline, 108′ AGL/128′ MSL. Mobile crane 3675′ from DER, 439′ right of centerline, 122′ AGL/145′ MSL. Ship rig 2440′ from DER, 34′ left of centerline, 176′ AGL/176′ MSL.
Rwy 22R: Ship rig 4064′ from DER, 8′ right of centerline, 176′ AGL/176′ MSL. Stacks beginning 1.4 NM from DER, 2795′ right of centerline, 320′ AGL/335′ MSL.
Rwy 27: Light pole and rod beginning 1690′ from DER, 759′ right of centerline, up to 60′ AGL/100′ MSL.
Rwy 33L: Electrical systems, buildings, chimney on building, and tank beginning 796′ from DER, 603′ left of centerline, up to 40′ AGL/149′ MSL. Sign, wind indicator on tower, and trees beginning 248′ from DER, 51′ right of centerline, up to 35′ AGL/101′ MSL. Bridge 1.4 NM from DER, 2568′ left of centerline, 262′ AGL/262′ MSL.

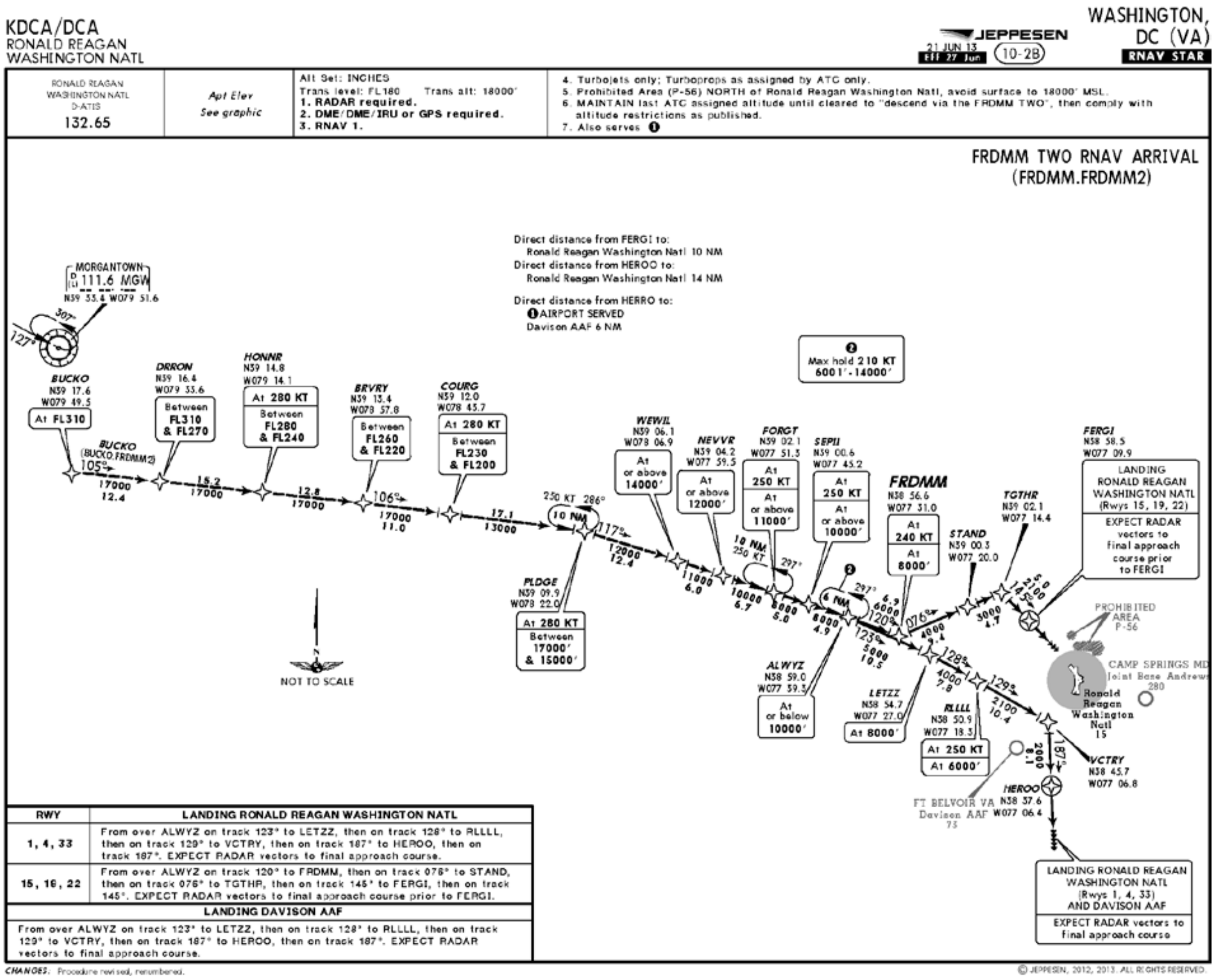
BLZZR TWO DEPARTURE (RNAV) BOSTON, MASSACHUSETTS

(BLZZR2.BLZZR) 13066 BOSTON / GENERAL EDWARD LAWRENCE LOGAN INTL (BOS)

FRDMM TWO RNAV

RNAV OPD arrival. Multiple window altitude constraints.

1. It is typical to have altitude constraints at such high altitudes? What is the typical altitude at which you enter/exit a STAR?
2. There are several speed constraints (280 kts, then 250 kts, and at FRDMM, 240 kts). How much workload do these constraints create?
3. Is it helpful to repeat the speed constraint even when there is no change?
4. Is 280 kts a reasonable speed constraint for your aircraft at altitudes in the ranges shown (FL280 to 11000)?
5. Discuss the lateral course. Is it typical to have such small variations in heading? Do they add workload?



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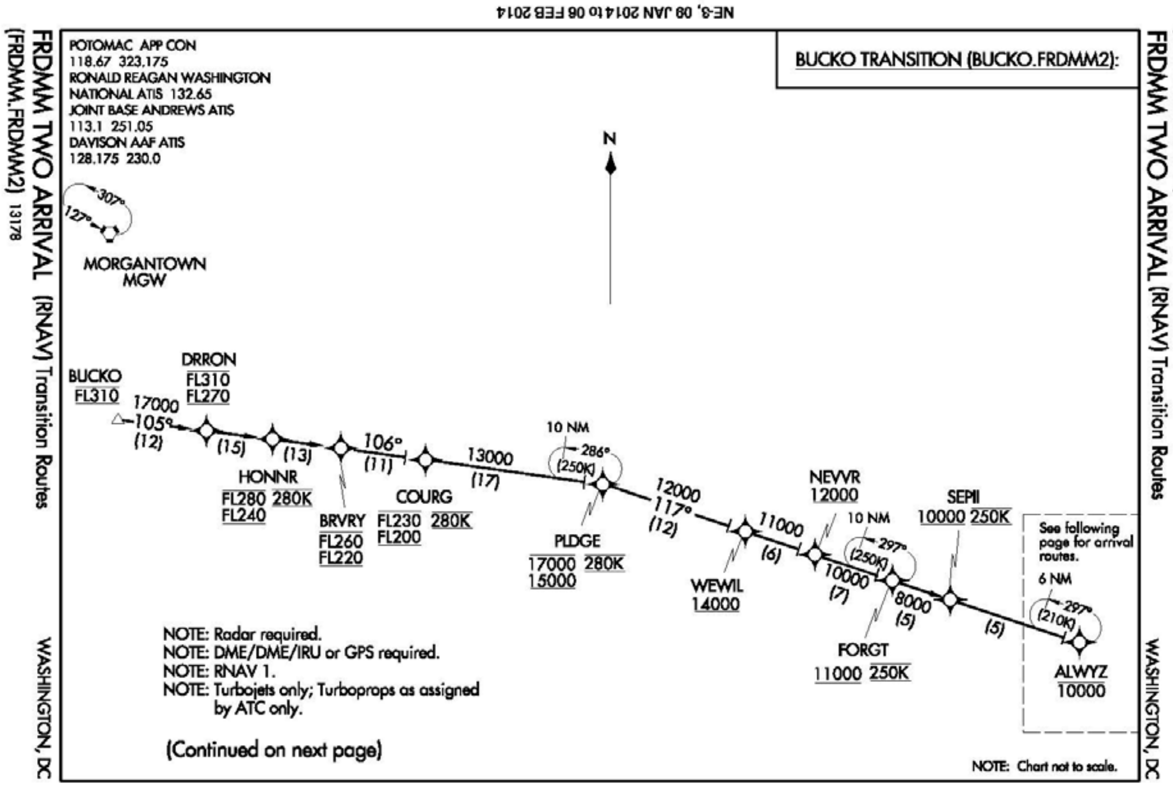
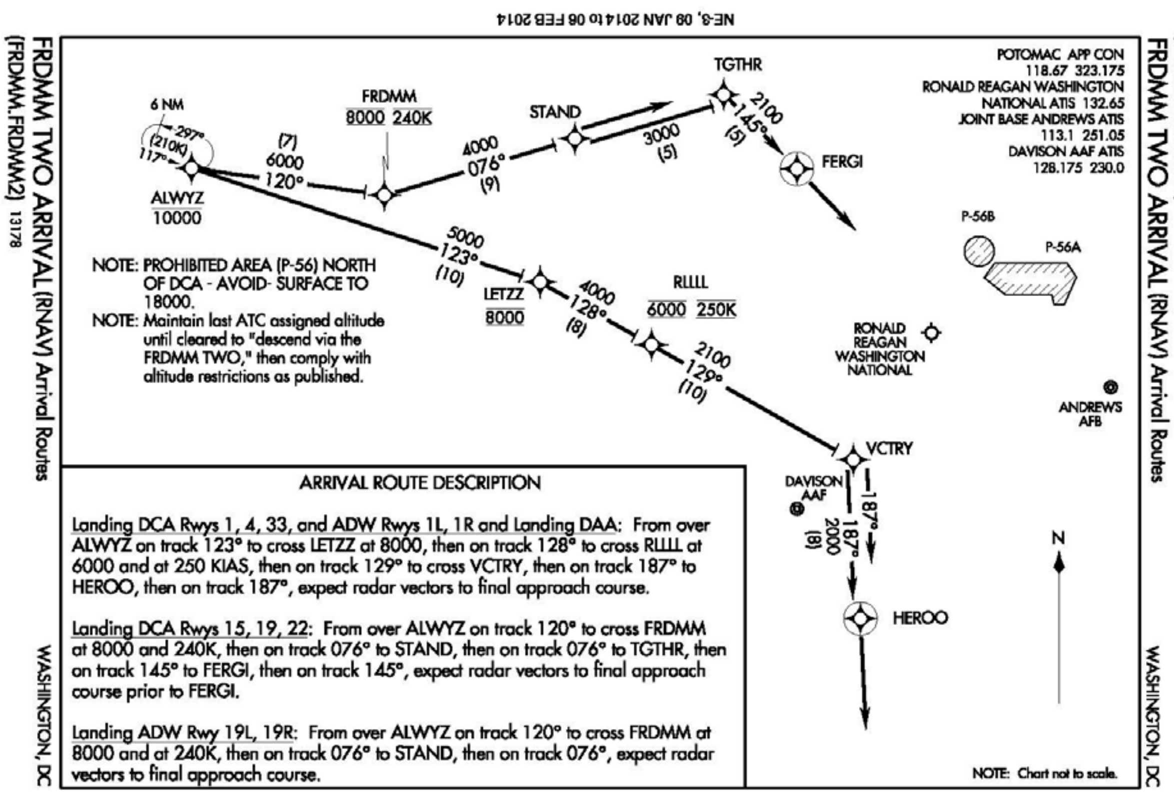


NE-3, 09 JAN 2014 to 06 FEB 2014

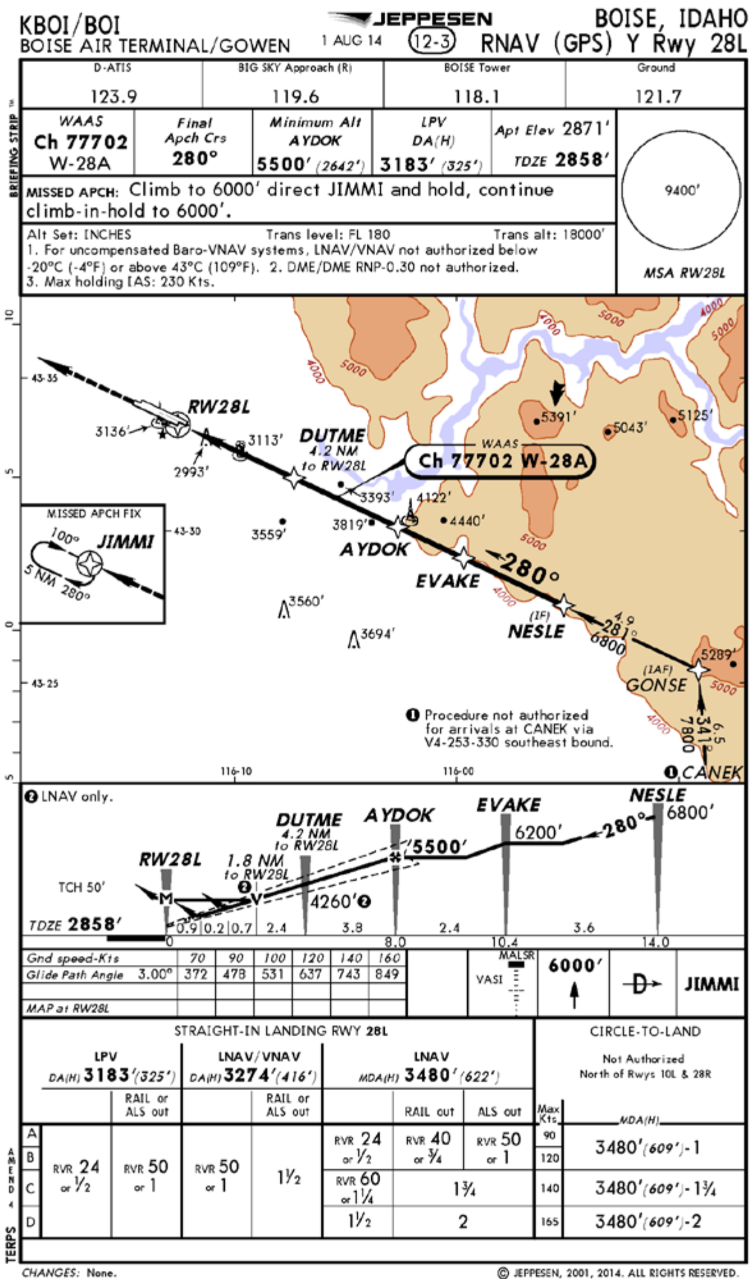


NE-3, 09 JAN 2014 to 06 FEB 2014

<u>Boise RNAV (GPS) Y 28L</u>

RNAV (GPS), for pilots who are not RNP AR qualified. LPV, LNAV/VNAV, and LNAV options.

1. Is the ball note in the profile view familiar? Is its meaning clear?
2. Did you notice that the missed approach procedure has a speed constraint? Is this common or unusual?
3. What is the significance of the intermediate fix at NESLE?



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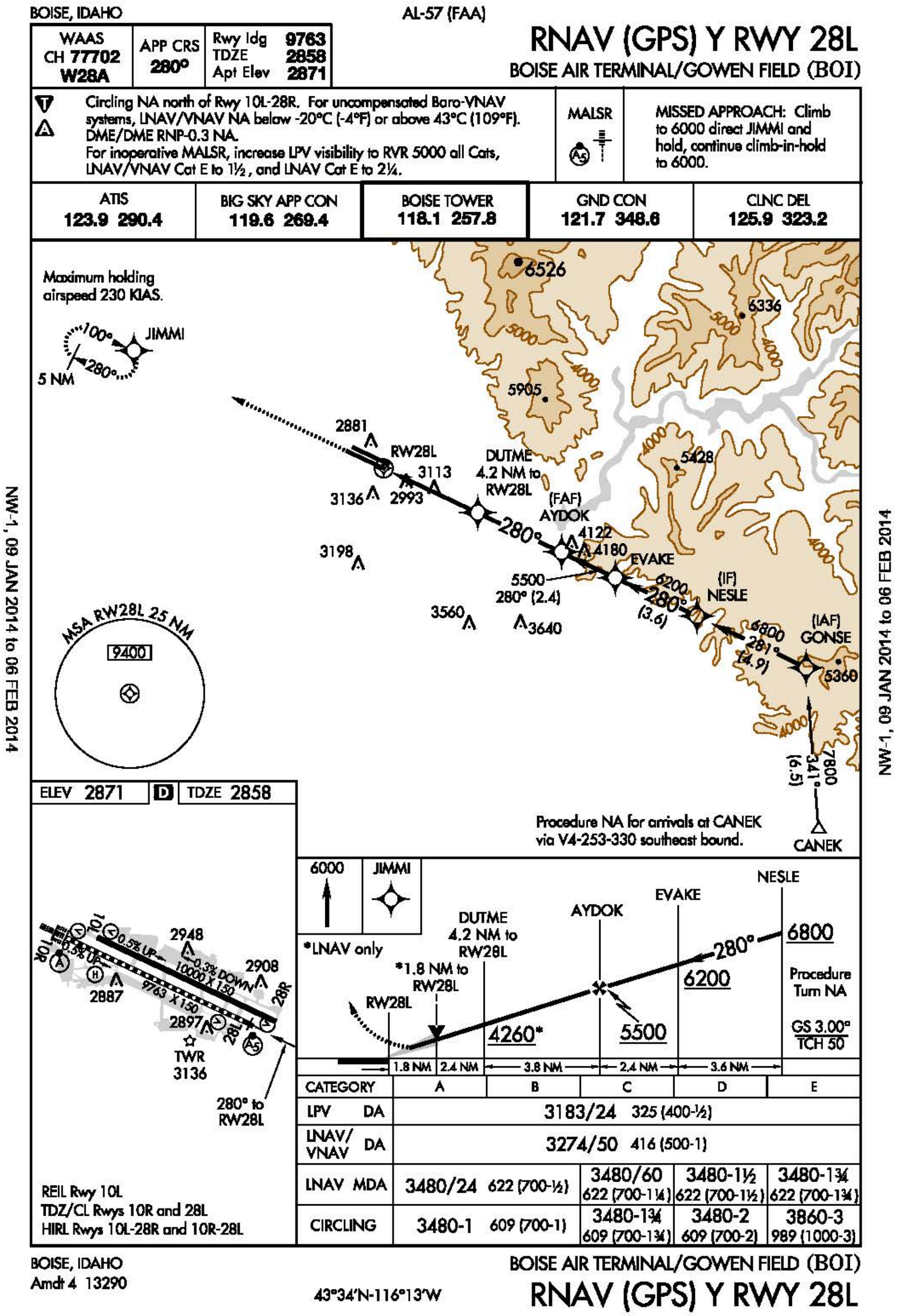
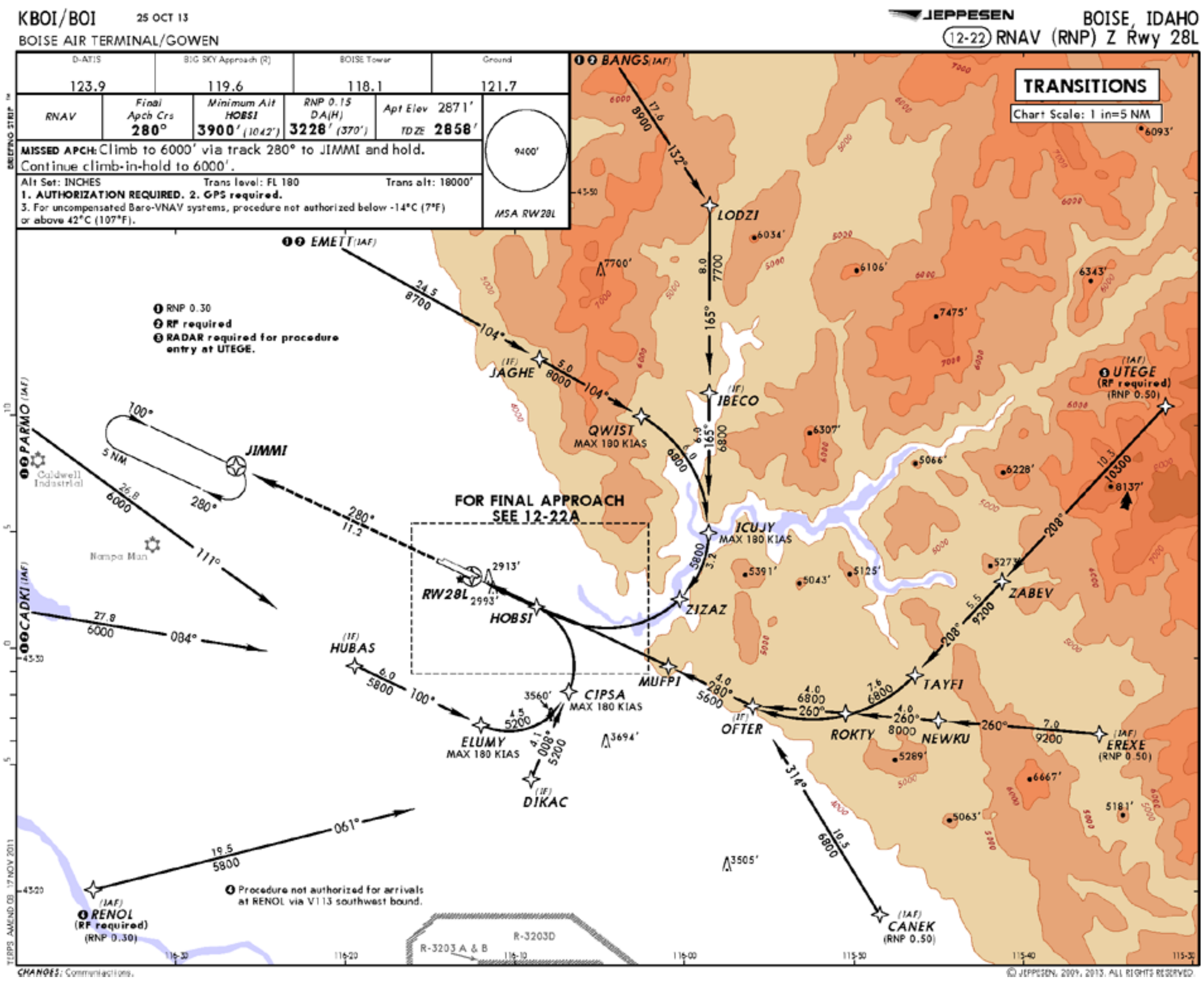

BOISE, IDAHO
AL-57 (FAA)
RNAV (GPS) Y RWY 28L
BOISE AIR TERMINAL/GOWEN FIELD (BOI)
WAAS
CH 77702
W28A
APP CRS
280°
Rwy ldg 9763
TDZE 2858
Apt Elev 2871
Circling NA north of Rwy 10L-28R. For uncompensated Baro-VNAV systems, LNAV/VNAV NA below -20°C (-4°F) or above 43°C (109°F).
DME/DME RNP-0.3 NA.
For inoperative MALSR, increase LPV visibility to RVR 5000 all Cats, LNAV/VNAV Cat E to 1½, and LNAV Cat E to 2¼.
MALSR
MISSED APPROACH: Climb to 6000 direct JIMMI and hold, continue climb-in-hold to 6000.
ATIS 123.9 290.4
BIG SKY APP CON 119.6 269.4
BOISE TOWER 118.1 257.8
GND CON 121.7 348.6
CLNC DEL 125.9 323.2
Maximum holding airspeed 230 KIAS.
JIMMI
100°
280°
5 NM
6526
6336
5905
5428
2881
RW28L
3113
DUTME
4.2 NM to RW28L
3136
2993
(FAF) AYDOK
4122
4180
EVAKE
3198
5500
280° (2.4)
6200
280°
(3.6)
(IF) NESLE
3560
3640
6800
281°
(4.9)
(IAF) GONSE
5360
MSA RW28L 25 NM
9400
7800
341°
(6.5)
CANEK
NW-1, 09 JAN 2014 to 06 FEB 2014
Procedure NA for arrivals at CANEK via V4-253-330 southeast bound.
ELEV 2871
D
TDZE 2858
2948
0.5% UP
10000 X 150
0.3% DOWN
2908
9763 X 150
2887
2897
TWR 3136
280° to RW28L
REIL Rwy 10L
TDZ/CL Rwys 10R and 28L
HIRL Rwys 10L-28R and 10R-28L
6000
JIMMI
*LNAV only
DUTME 4.2 NM to RW28L
*1.8 NM to RW28L
RW28L
AYDOK
EVAKE
NESLE
6800
280°
6200
Procedure Turn NA
4260*
5500
GS 3.00°
TCH 50
1.8 NM
2.4 NM
3.8 NM
2.4 NM
3.6 NM
CATEGORY A B C D E
LPV DA 3183/24 325 (400-½)
LNAV/VNAV DA 3274/50 416 (500-1)
LNAV MDA 3480/24 622 (700-½) 3480/60 622 (700-1¼) 3480-1½ 622 (700-1½) 3480-1¾ 622 (700-1¾)
CIRCLING 3480-1 609 (700-1) 3480-1¾ 609 (700-1¾) 3480-2 609 (700-2) 3860-3 989 (1000-3)
BOISE, IDAHO
Amdt 4 13290
43°34'N-116°13'W
BOISE AIR TERMINAL/GOWEN FIELD (BOI)
RNAV (GPS) Y RWY 28L

Boise RNAV (RNP) Z RWY 28L

RNAV (RNP) AR approach with multiple transitions for qualified pilots. This IFP and its chart were updated (simplified) after data collection was completed.

1. Discuss the way this procedure is broken into two chart pages [Jeppesen format only]. Is it easy to understand how the pages are related?
2. How do you use the vertical profile view? Does this vertical profile view begin where you expected it to?
3. This procedure is “authorization required” meaning that crews have to be specially trained and aircraft must be specially equipped. Do you anticipate a similar procedure (with multiple approach transitions and vertical profiles) could be made public (i.e., no “authorization required”)?



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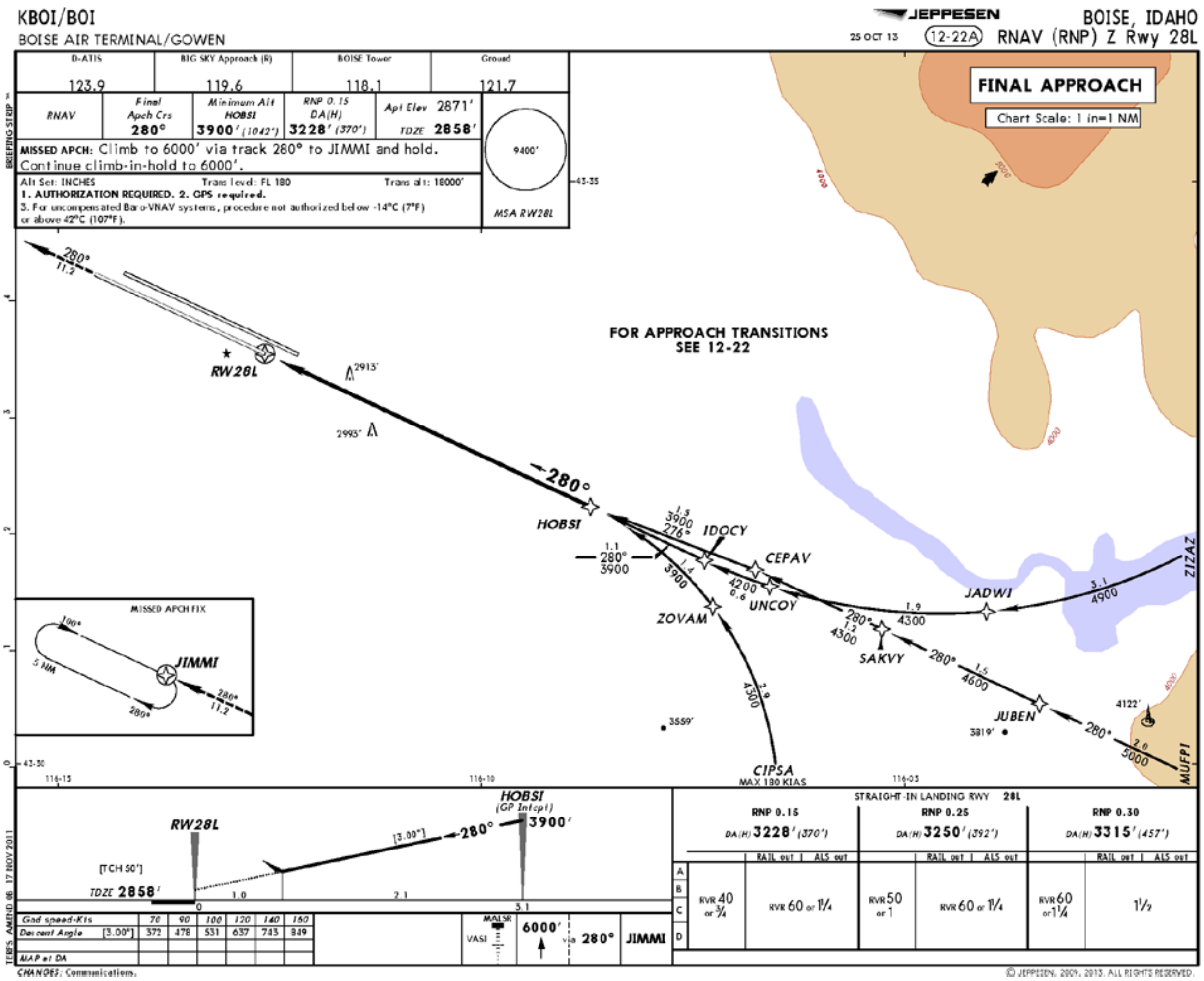

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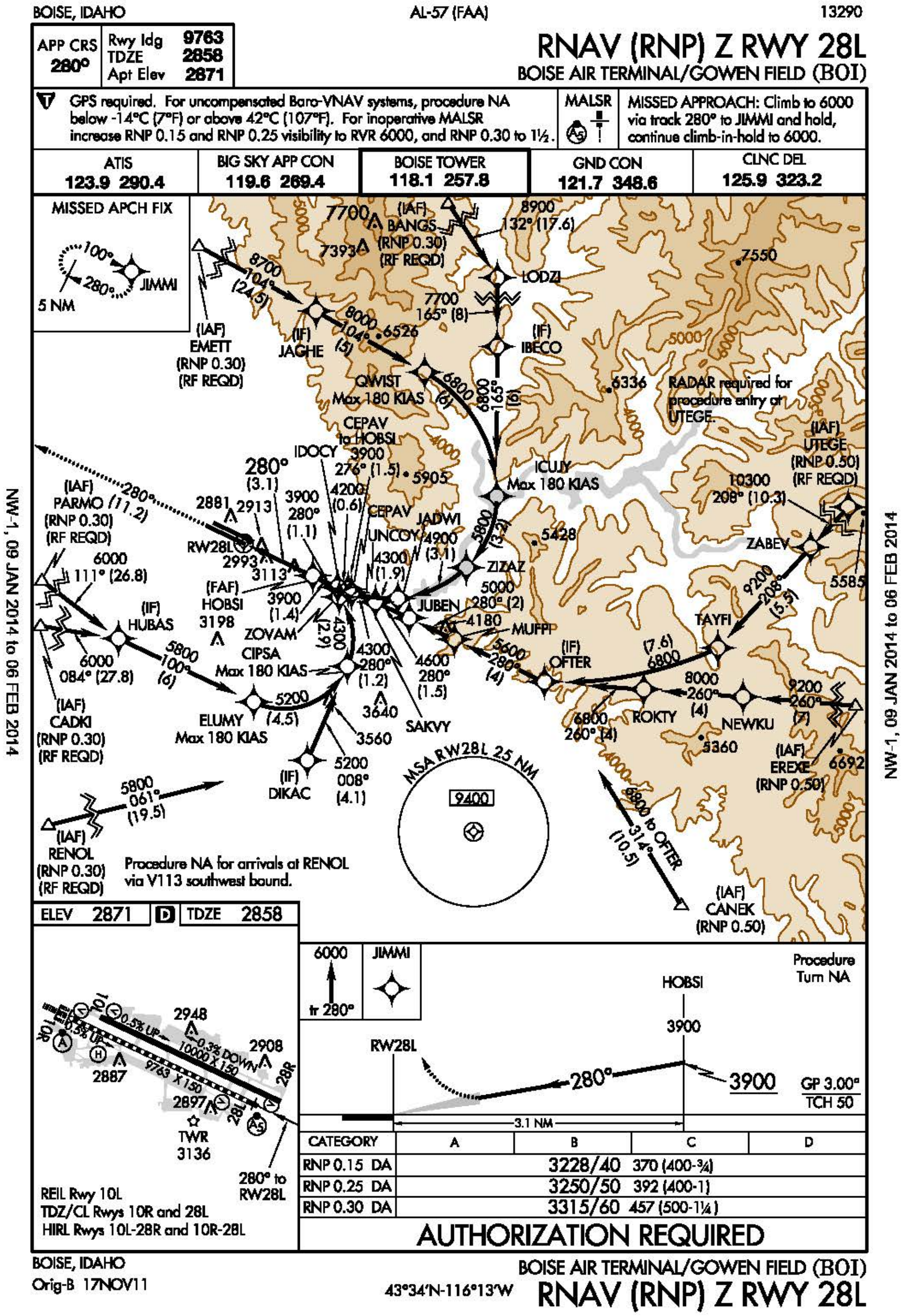
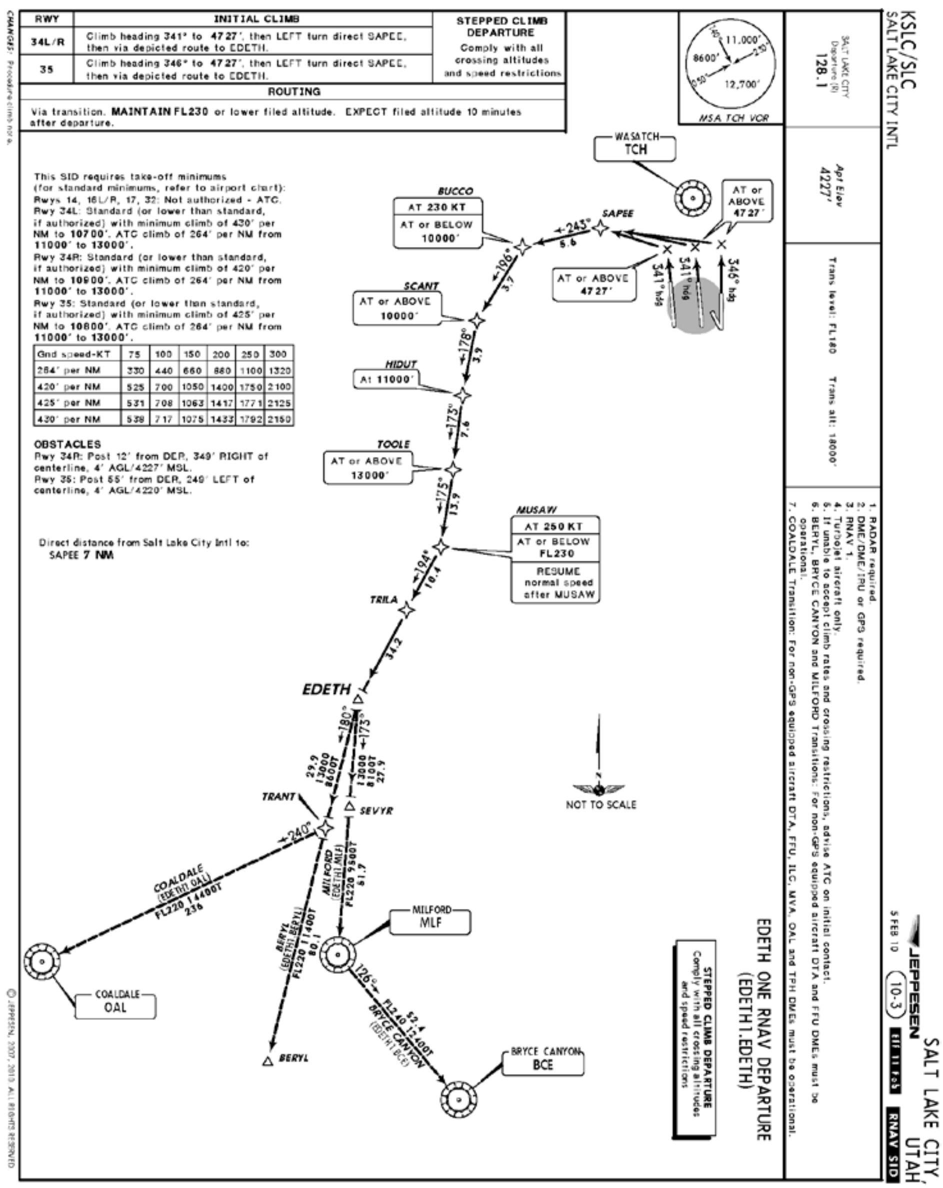


BOISE, IDAHO
AL-57 (FAA)
13290
APP CRS 280°
Rwy ldg 9763
TDZE 2858
Apt Elev 2871
RNAV (RNP) Z RWY 28L
BOISE AIR TERMINAL/GOWEN FIELD (BOI)
GPS required. For uncompensated Baro-VNAV systems, procedure NA below -14°C (7°F) or above 42°C (107°F). For inoperative MALSR increase RNP 0.15 and RNP 0.25 visibility to RVR 6000, and RNP 0.30 to 1½.
MALSR
MISSED APPROACH: Climb to 6000 via track 280° to JIMMI and hold, continue climb-in-hold to 6000.
ATIS 123.9 290.4
BIG SKY APP CON 119.6 269.4
BOISE TOWER 118.1 257.8
GND CON 121.7 348.6
CLNC DEL 125.9 323.2
MISSED APCH FIX
JIMMI
5 NM
(IAF) BANGS (RNP 0.30) (RF REQD)
(IAF) EMETT (RNP 0.30) (RF REQD)
(IF) JAGHE
QWIST Max 180 KIAS
LODZI
(IF) IBECO
RADAR required for procedure entry at UTEGE.
(IAF) UTEGE (RNP 0.50) (RF REQD)
ICUJY Max 180 KIAS
(IAF) PARMO (RNP 0.30) (RF REQD)
RW28L
(FAF) HOBSI
ZOVAM
CIPSA Max 180 KIAS
(IF) HUBAS
ELUMY Max 180 KIAS
(IF) DIKAC
(IAF) CADKI (RNP 0.30) (RF REQD)
JUBEN
ZIZAZ
MUFFI
(IF) OFTER
ROKTY
NEWKU
TAYFI
ZABEV
(IAF) EREXE (RNP 0.50)
MSA RW28L 25 NM
9400
(IAF) RENOL (RNP 0.30) (RF REQD)
Procedure NA for arrivals at RENOL via V113 southwest bound.
(IAF) CANEK (RNP 0.50)
NW-1, 09 JAN 2014 to 06 FEB 2014
ELEV 2871
TDZE 2858
REIL Rwy 10L
TDZ/CL Rwys 10R and 28L
HIRL Rwys 10L-28R and 10R-28L
Procedure Turn NA
HOBSI
3900
GP 3.00°
TCH 50
3.1 NM
CATEGORY A B C D
RNP 0.15 DA 3228/40 370 (400-¾)
RNP 0.25 DA 3250/50 392 (400-1)
RNP 0.30 DA 3315/60 457 (500-1¼)
AUTHORIZATION REQUIRED
BOISE, IDAHO
Orig-B 17NOV11
43°34'N-116°13'W
BOISE AIR TERMINAL/GOWEN FIELD (BOI)
RNAV (RNP) Z RWY 28L

EDETH ONE RNAV

RNAV departure with short runway transitions, a common segment, and three long enroute transitions.

1. Jeppesen labels this a “Stepped Climb Departure.” What does that mean?
2. How would you set up the MCP and FMS to fly this procedure?
3. Which waypoints would you verify as you flew over them? What do you do to verify a waypoint?
4. There are two minimum altitudes on the segments. Explain how you use each of these. What does the “T” next to an altitude indicate?
5. Did you notice the length of this procedure? Is that typical?
6. The chart is not to scale. Does that affect how you use it?



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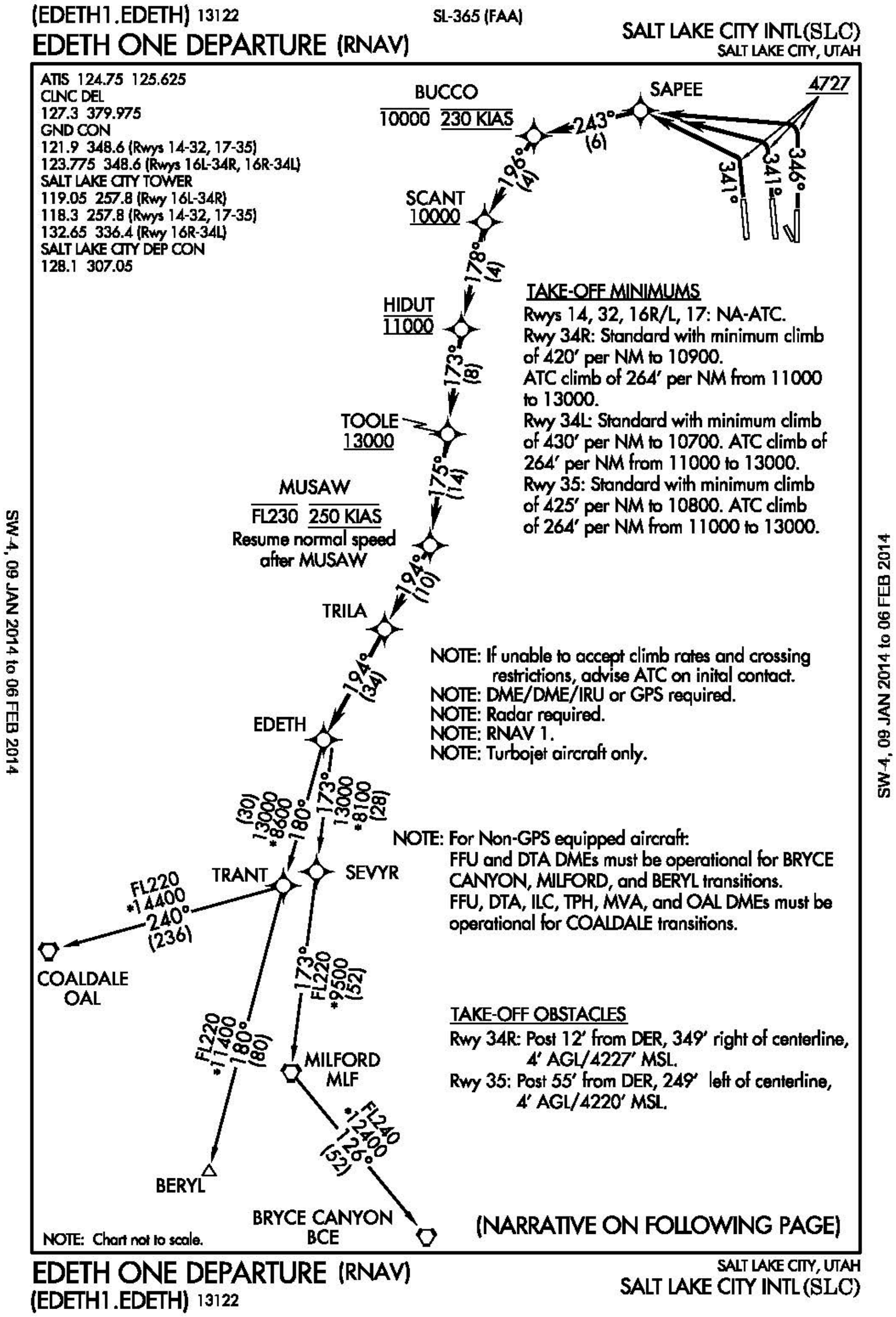

(EDETH1.EDETH) 13122
SL-365 (FAA)
EDETH ONE DEPARTURE (RNAV)
SALT LAKE CITY INTL(SLC)
SALT LAKE CITY, UTAH
ATIS 124.75 125.625
CLNC DEL
127.3 379.975
GND CON
121.9 348.6 (Rwys 14-32, 17-35)
123.775 348.6 (Rwys 16L-34R, 16R-34L)
SALT LAKE CITY TOWER
119.05 257.8 (Rwy 16L-34R)
118.3 257.8 (Rwys 14-32, 17-35)
132.65 336.4 (Rwy 16R-34L)
SALT LAKE CITY DEP CON
128.1 307.05
BUCCO
10000 230 KIAS
SAPEE
4727
243° (6)
341°
341°
346°
196° (4)
SCANT
10000
178° (4)
HIDUT
11000
173° (8)
TOOLE
13000
175° (14)
MUSAW
FL230 250 KIAS
Resume normal speed after MUSAW
194° (10)
TRILA
194° (34)
EDETH
180° 13000 *8600 (30)
173° 13000 *8100 (28)
TRANT
SEVYR
FL220 *14400 240° (236)
COALDALE
OAL
173° FL220 *9500 (52)
FL220 *11400 180° (80)
MILFORD
MLF
FL240 *12400 126° (52)
BERYL
BRYCE CANYON
BCE
TAKE-OFF MINIMUMS
Rwys 14, 32, 16R/L, 17: NA-ATC.
Rwy 34R: Standard with minimum climb of 420' per NM to 10900. ATC climb of 264' per NM from 11000 to 13000.
Rwy 34L: Standard with minimum climb of 430' per NM to 10700. ATC climb of 264' per NM from 11000 to 13000.
Rwy 35: Standard with minimum climb of 425' per NM to 10800. ATC climb of 264' per NM from 11000 to 13000.
NOTE: If unable to accept climb rates and crossing restrictions, advise ATC on inital contact.
NOTE: DME/DME/IRU or GPS required.
NOTE: Radar required.
NOTE: RNAV 1.
NOTE: Turbojet aircraft only.
NOTE: For Non-GPS equipped aircraft: FFU and DTA DMEs must be operational for BRYCE CANYON, MILFORD, and BERYL transitions. FFU, DTA, ILC, TPH, MVA, and OAL DMEs must be operational for COALDALE transitions.
TAKE-OFF OBSTACLES
Rwy 34R: Post 12' from DER, 349' right of centerline, 4' AGL/4227' MSL.
Rwy 35: Post 55' from DER, 249' left of centerline, 4' AGL/4220' MSL.
NOTE: Chart not to scale.
(NARRATIVE ON FOLLOWING PAGE)
EDETH ONE DEPARTURE (RNAV)
(EDETH1.EDETH) 13122
SALT LAKE CITY, UTAH
SALT LAKE CITY INTL(SLC)
SW-4, 09 JAN 2014 to 06 FEB 2014
SW-4, 09 JAN 2014 to 06 FEB 2014

(EDETH1.EDETH) 07354 SL-365 (FAA)

EDETH ONE DEPARTURE (RNAV)

SALT LAKE CITY INTL(SLC)
SALT LAKE CITY, UTAH

SW-4, 09 JAN 2014 to 06 FEB 2014

DEPARTURE ROUTE DESCRIPTION

TAKE-OFF RUNWAY 34R: Climb heading 341° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .
TAKE-OFF RUNWAY 34L: Climb heading 341° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .
TAKE-OFF RUNWAY 35: Climb heading 346° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .

. . . .via (transition) maintain FL230 or lower filed altitude. Expect filed altitude 10 minutes after departure.

BERYL TRANSITION (EDETH1.BERYL)
BRYCE CANYON TRANSITION (EDETH1.BCE)
COALDALE TRANSITION (EDETH1.OAL)
MILFORD TRANSITION (EDETH1.MLF)

SW-4, 09 JAN 2014 to 06 FEB 2014

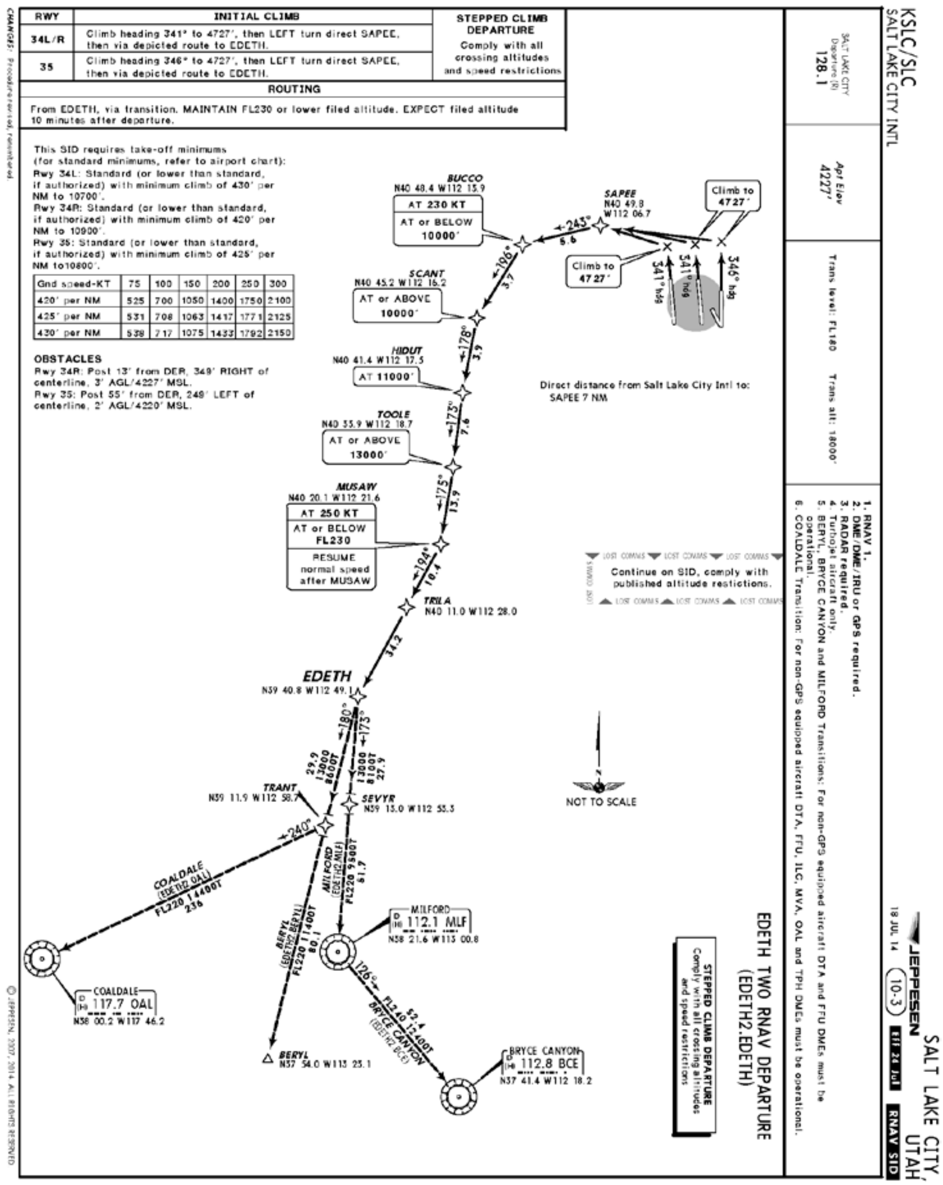
EDETH ONE DEPARTURE (RNAV)
(EDETH1.EDETH) 07354
SALT LAKE CITY, UTAH
SALT LAKE CITY INTL (SLC)

EDETH TWO RNAV

Same questions as for EDETH One

Changes effective 10 July 2014

- Deleted MSA
- Added Latitude-longitude to waypoints
- Added VOR/DME data
- Added Lost Communications procedures
- Bolded and reordered notes in the briefing information
- Moved MUSAW constraint box to left side of path



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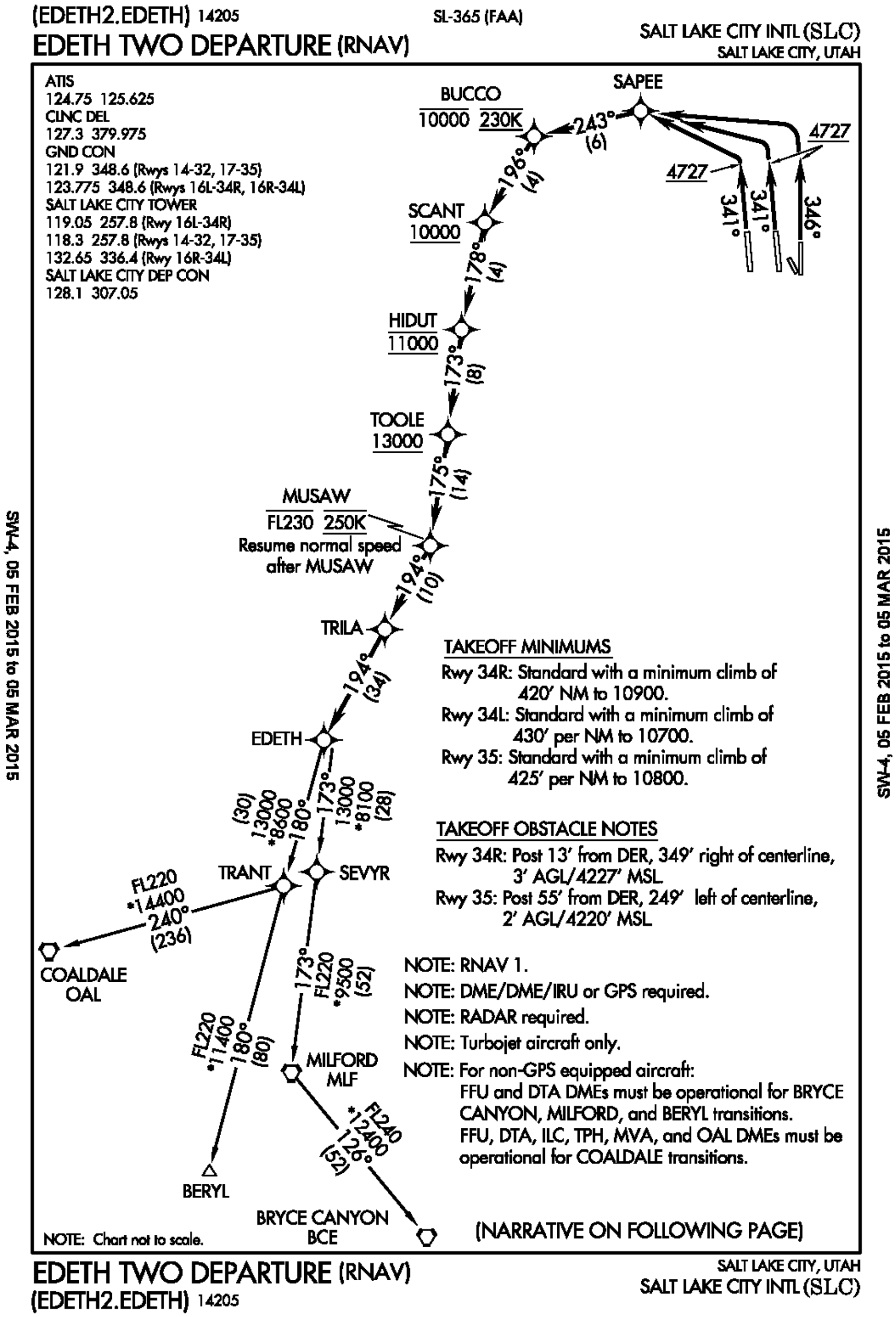

(EDETH2.EDETH) 14205
SL-365 (FAA)
EDETH TWO DEPARTURE (RNAV)
SALT LAKE CITY INTL (SLC)
SALT LAKE CITY, UTAH
ATIS
124.75 125.625
CLNC DEL
127.3 379.975
GND CON
121.9 348.6 (Rwys 14-32, 17-35)
123.775 348.6 (Rwys 16L-34R, 16R-34L)
SALT LAKE CITY TOWER
119.05 257.8 (Rwy 16L-34R)
118.3 257.8 (Rwys 14-32, 17-35)
132.65 336.4 (Rwy 16R-34L)
SALT LAKE CITY DEP CON
128.1 307.05
SAPEE
BUCCO
10000 230K
243° (6)
4727
341°
341°
346°
196° (4)
SCANT
10000
178° (4)
HIDUT
11000
173° (8)
TOOLE
13000
175° (14)
MUSAW
FL230 250K
Resume normal speed after MUSAW
194° (10)
TRILA
194° (34)
EDETH
180° *8600 13000 (30)
173° 13000 *8100 (28)
TRANT
SEVYR
FL220 *14400 240° (236)
COALDALE OAL
173° FL220 *9500 (52)
FL220 *11400 180° (80)
MILFORD MLF
FL240 *12400 126° (52)
BERYL
BRYCE CANYON BCE
TAKEOFF MINIMUMS
Rwy 34R: Standard with a minimum climb of 420′ NM to 10900.
Rwy 34L: Standard with a minimum climb of 430′ per NM to 10700.
Rwy 35: Standard with a minimum climb of 425′ per NM to 10800.
TAKEOFF OBSTACLE NOTES
Rwy 34R: Post 13′ from DER, 349′ right of centerline, 3′ AGL/4227′ MSL.
Rwy 35: Post 55′ from DER, 249′ left of centerline, 2′ AGL/4220′ MSL.
NOTE: RNAV 1.
NOTE: DME/DME/IRU or GPS required.
NOTE: RADAR required.
NOTE: Turbojet aircraft only.
NOTE: For non-GPS equipped aircraft:
FFU and DTA DMEs must be operational for BRYCE CANYON, MILFORD, and BERYL transitions.
FFU, DTA, ILC, TPH, MVA, and OAL DMEs must be operational for COALDALE transitions.
NOTE: Chart not to scale.
(NARRATIVE ON FOLLOWING PAGE)
EDETH TWO DEPARTURE (RNAV)
(EDETH2.EDETH) 14205
SALT LAKE CITY, UTAH
SALT LAKE CITY INTL (SLC)
SW-4, 05 FEB 2015 to 05 MAR 2015

(EDETH2.EDETH) 14205 SL-365 (FAA)

EDETH TWO DEPARTURE (RNAV)

SALT LAKE CITY INTL(SLC)
SALT LAKE CITY, UTAH

SW-4, 05 FEB 2015 to 05 MAR 2015

DEPARTURE ROUTE DESCRIPTION

TAKEOFF RUNWAY 34R: Climb heading 341° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .
TAKEOFF RUNWAY 34L: Climb heading 341° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .
TAKEOFF RUNWAY 35: Climb heading 346° to 4727, then left turn direct SAPEE, then via depicted route to EDETH, thence. . . .

. . . .via (transition) maintain FL230 or lower filed altitude. Expect filed altitude 10 minutes after departure.

BERYL TRANSITION (EDETH2.BERYL)
BRYCE CANYON TRANSITION (EDETH2.BCE)
COALDALE TRANSITION (EDETH2.OAL)
MILFORD TRANSITION (EDETH2.MLF)

LOST COMMUNICATIONS: Continue on SID. Comply with published altitude restrictions.

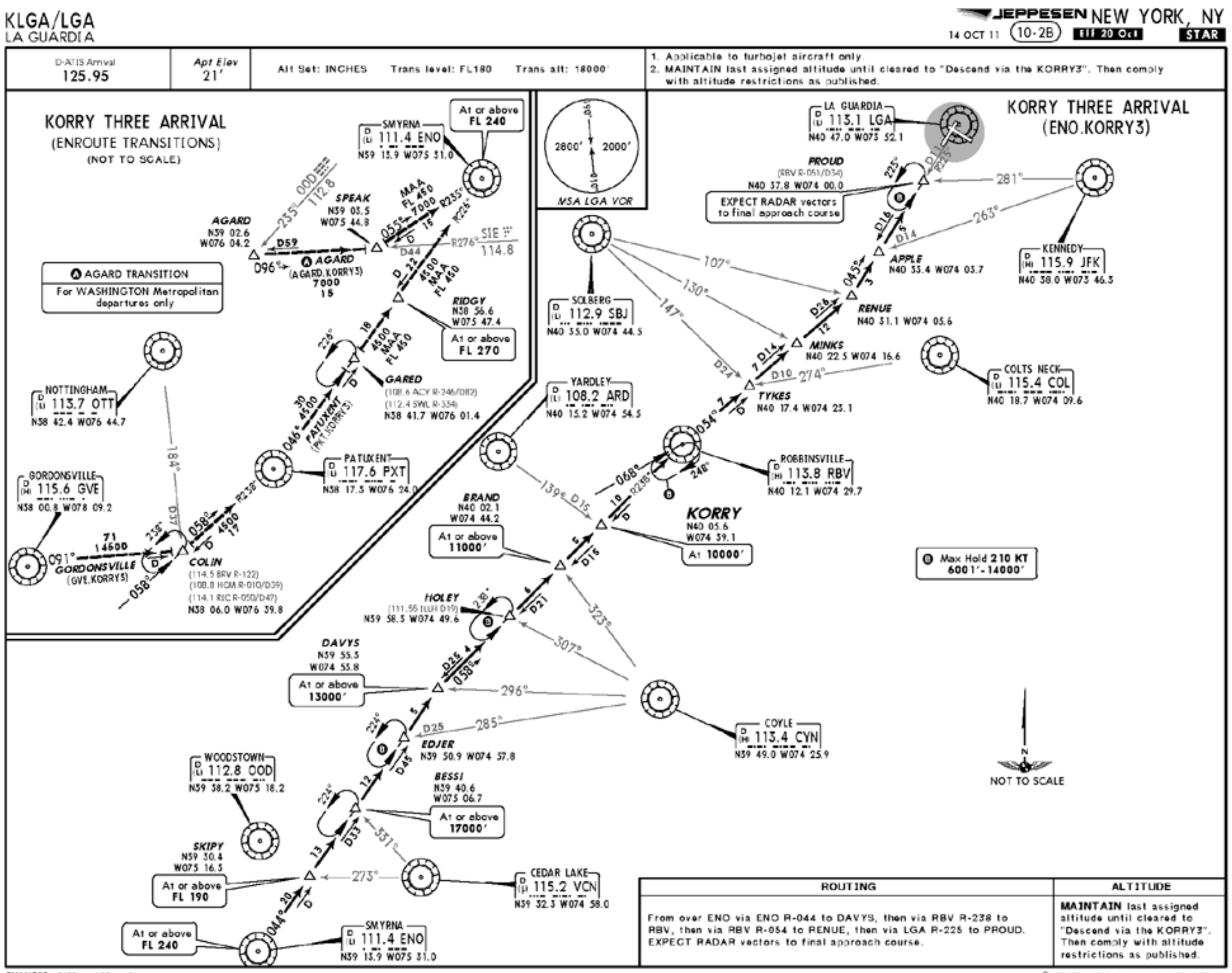
SW-4, 05 FEB 2015 to 05 MAR 2015

EDETH TWO DEPARTURE (RNAV)
(EDETH2.EDETH) 14205
SALT LAKE CITY, UTAH
SALT LAKE CITY INTL (SLC)

KORRY THREE

Conventional arrival with VOR radials.

1. Discuss the way this chart is broken into sections.
2. Is this a cluttered chart? Is it hard to use because of the clutter?
3. How does this procedure compare to the FRDMM arrival?
4. The chart mentions the phrase “Descend Via the KORRY 3.” Is it clear to you what that means?



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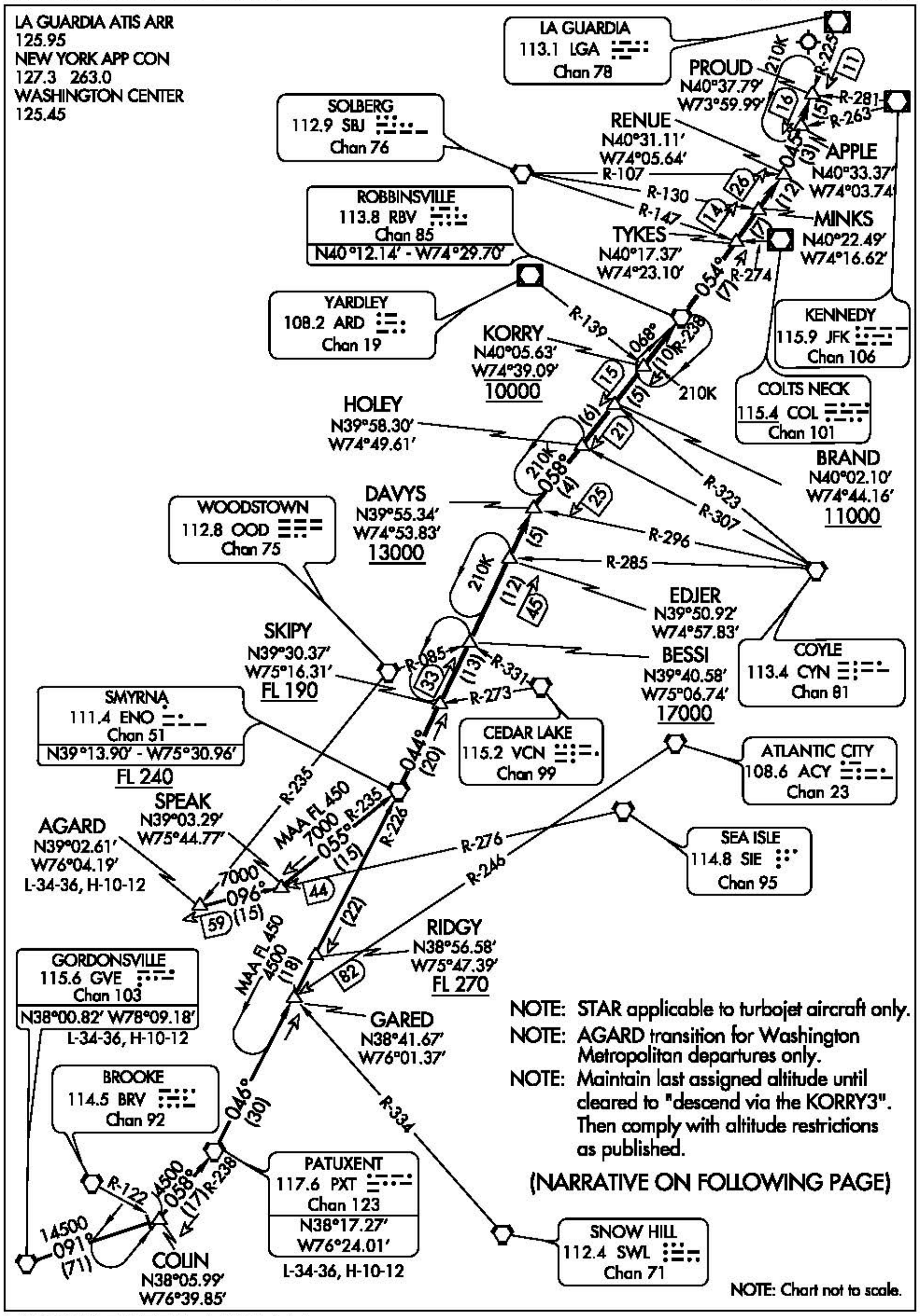
(ENO.KORRY3) 11237 ST-289 (FAA)

KORRY THREE ARRIVAL

LA GUARDIA
NEW YORK, NEW YORK

NE-2, 09 JAN 2014 to 06 FEB 2014



NE-2, 09 JAN 2014 to 06 FEB 2014

KORRY THREE ARRIVAL
(ENO.KORRY3) 11237

NEW YORK, NEW YORK
LA GUARDIA

NE-2, 09 JAN 2014 to 06 FEB 2014

ARRIVAL ROUTE DESCRIPTION

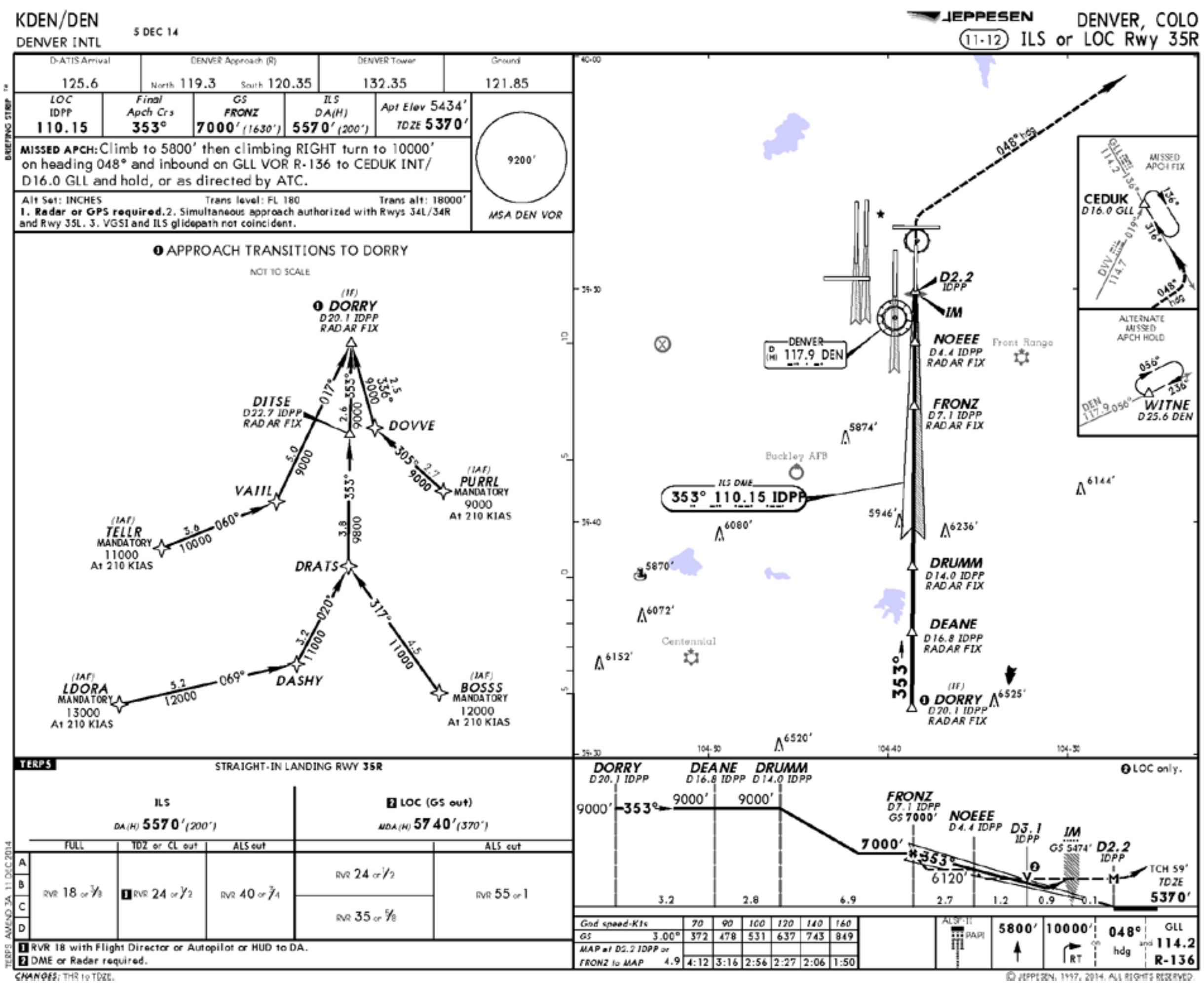
AGARD TRANSITION (AGARD.KORRY3): From over AGARD INT via SIE R-276 and ENO R-235 to ENO VORTAC. Thence . . . .
GORDONSVILLE TRANSITION (GVE.KORRY3): From over GVE VORTAC via GVE R-091 and PXT R-238 to PXT VORTAC, then via PXT R-046 and ENO R-226 to ENO VORTAC. Thence . . . .
PATUXENT TRANSITION (PXT.KORRY3): From over PXT VORTAC via PXT R-046 and ENO R-226 to ENO VORTAC. Thence . . . .
. . . . From over ENO VORTAC via ENO R-044 to DAVYS INT, then via RBV R-238 to RBV VORTAC, then via RBV R-054 to RENUE INT, then via LGA R-225 to PROUD INT. Expect radar vectors to final approach course.

NE-2, 09 JAN 2014 to 06 FEB 2014

Denver ILS/LOC RWY 35R

RNAV transitions to ILS.

1. Is the depiction clear?
2. Did you notice that the RNAV transition is not depicted to scale but the ILS section is to scale? Is that easy to understand?
3. Do you anticipate any difficulties in flying this procedure?
4. At what point would you arm the localizer capture mode when arriving via DRATS?



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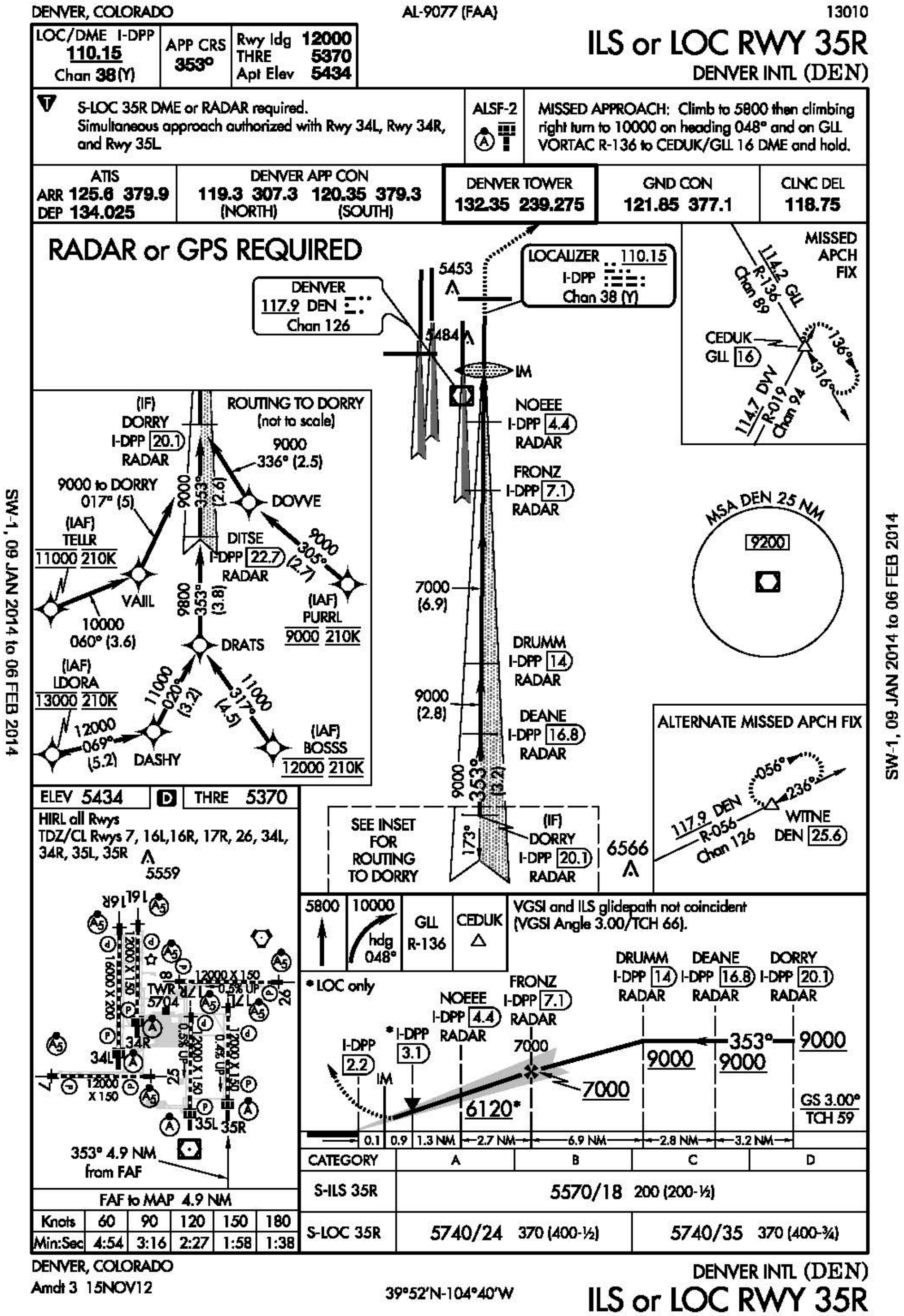
DENVER, COLORADO
AL-9077 (FAA)
13010
ILS or LOC RWY 35R
DENVER INTL (DEN)
LOC/DME I-DPP 110.15 Chan 38(Y)
APP CRS 353°
Rwy ldg 12000
THRE 5370
Apt Elev 5434
S-LOC 35R DME or RADAR required.
Simultaneous approach authorized with Rwy 34L, Rwy 34R, and Rwy 35L.
ALSF-2
MISSED APPROACH: Climb to 5800 then climbing right turn to 10000 on heading 048° and on GLL VORTAC R-136 to CEDUK/GLL 16 DME and hold.
ATIS ARR 125.6 379.9 DEP 134.025
DENVER APP CON 119.3 307.3 (NORTH) 120.35 379.3 (SOUTH)
DENVER TOWER 132.35 239.275
GND CON 121.85 377.1
CLNC DEL 118.75
RADAR or GPS REQUIRED
DENVER 117.9 DEN Chan 126
LOCALIZER 110.15 I-DPP Chan 38 (Y)
MISSED APCH FIX
114.2 GLL R-136 Chan 89
CEDUK GLL 16
114.7 DVV R-019 Chan 94
ROUTING TO DORRY (not to scale)
(IF) DORRY I-DPP 20.1 RADAR
9000 336° (2.5)
DOWE
9000 to DORRY 017° (5)
(IAF) TELLR 11000 210K
DITSE I-DPP 22.7 RADAR
9000 305° (2.7)
VAIIL
10000 060° (3.6)
(IAF) PURRL 9000 210K
DRATS
(IAF) LDORA 13000 210K
11000 020° (3.2)
11000 317° (4.5)
12000 069° (5.2)
DASHY
(IAF) BOSSS 12000 210K
NOEEE I-DPP 4.4 RADAR
FRONZ I-DPP 7.1 RADAR
DRUMM I-DPP 14 RADAR
DEANE I-DPP 16.8 RADAR
7000 (6.9)
9000 (2.8)
MSA DEN 25 NM 9200
ALTERNATE MISSED APCH FIX
117.9 DEN R-056 Chan 126
WITNE DEN 25.6
SEE INSET FOR ROUTING TO DORRY
6566
ELEV 5434
THRE 5370
HIRL all Rwys
TDZ/CL Rwys 7, 16L,16R, 17R, 26, 34L, 34R, 35L, 35R
5559
353° 4.9 NM from FAF
FAF to MAP 4.9 NM
5800
10000 hdg 048°
GLL R-136
CEDUK
VGSI and ILS glidepath not coincident (VGSI Angle 3.00/TCH 66).
*LOC only
GS 3.00° TCH 59
6120*
CATEGORY A B C D
S-ILS 35R 5570/18 200 (200-½)
S-LOC 35R 5740/24 370 (400-½) 5740/35 370 (400-¾)
Knots 60 90 120 150 180
Min:Sec 4:54 3:16 2:27 1:58 1:38
SW-1, 09 JAN 2014 to 06 FEB 2014
DENVER, COLORADO
Amdt 3 15NOV12
39°52'N-104°40'W
DENVER INTL (DEN)
ILS or LOC RWY 35R

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Appendix C: Participant and Group Highlights

Group	Type of Pilots	Number of Participants	RNP AR Qualified?	Additional Information
1	Corporate 1	3	Yes	• Have flown 60-70 RNP approaches • Especially thorough and consistent briefings • High-end avionics • European flight experience
2	Major Airline 1	3	Yes	• Two participants knew each other • All fly two different types of the same aircraft—one with more advanced avionics than the other
3	Major Airline 1	2	Yes	• Both First Officers • All fly two different types of the same aircraft—one with more advanced avionics than the other
4	Major Airline 2	2	Yes	• Participants flew different aircraft models made by the same manufacturer • One participant flew with an older FMS with more human interface issues • One participant had European flight experience
5	Major Airline 2	3	Yes	• Two participants with military experience • One participant familiar with European routes
6	Major Airline 2	1	Yes	• Former Navy pilot (experienced with carrier landings) • Has not flown RNP procedure on the line • Second participant canceled last minute
7	Major Airline 3	2	Yes	• First group to use EDETH TWO
8	Major Airline 3	2	Yes	• Have not flown RNP on the line in past year • Fly Eastern half of Continental US
9	Major Airline 3	2	Yes	• Fly Eastern half of Continental US
10	Major Airline 3	3	Yes	• Have flown RNP at JFK Airport, New York and Long Beach, California
11	Air Taxi	3	No	• First review of Boise RNAV (GPS) Y 28L • Have flown just one LNAV procedure in past year
12	Air Taxi (Management)	2	No	• Both participants worked in the Training Department (not line pilots) • Fly EDETH in simulator to train LNAV and VNAV
13	Air Taxi	2	No	• One participant had international flight experience the other did not • Participant with international experience flies in western US (with GPS approaches). Domestic pilot flies in Eastern US, where ILS is the norm

Group	Type of Pilots	Number of Participants	RNP AR Qualified?	Additional Information
14	Regional	2	No	• One captain, one First Officer (flew together past few days) • Flights of 4 hours or shorter. US, Mexico, Canada
15	Regional	2	No	• Fly into the Rocky Mountains and Mexico. Usually fly Eastern 2/3 of US, as far as ABQ and Grand Junction, Colorado.
16	Regional	2	No	• Do not typically fly in the mountains • Short flights (less than 2 hours). Stay on east coast. • Use paper charts
17	Corporate 2	3	No	• Mostly domestic routes, 25% international, medium to large airports
18	Corporate 3	3	No	• Participants have flown together for decades • New airplane (less than 5 years old) • Mostly domestic routes, 4-6 hours. Some European flights. Some to Colorado Rockies.
19	Corporate 3	3	No	• Also discussed another aircraft model from the same manufacturer • Crew flies US domestic routes, does go into mountains • Crew is familiar with European operations on the other aircraft model

Appendix D: Introductory and Concluding Materials

Introduction

The goal of this study is to explore aspects of procedure design and depiction that are associated with subjective complexity for line pilots.

We would like to understand how you review and use procedures. Our goal is to develop this understanding to improve the design of future instrument procedures.

You will talk through the procedures that we show to you. You may use either the hard copy of the chart, the iPad, or both.

RNAV procedures are the focus of the study, but a conventional procedure is included for comparison. We will show you two SIDs, two STARs, and two IAPs. We will listen to you discuss the procedures and then ask you some questions about it.

We will be taking notes on the conversation and may ask you clarification questions if needed.

You will not be flying any of the procedures and we will not record the time spent on each chart.

We expect to take about 3 hours, with planned breaks between each type of procedure. *[We can also take a longer break for lunch if needed.]*

The results of the study will inform designers about potential for confusion in the procedure design. This study will also help us to understand how charts are used in normal operations in the context of modern flight deck systems. This knowledge will be helpful in identifying areas of improvement in charts and procedures.

Please consider all types of complexity and potential for confusion.

We need your full attention for the study, so please do not use your cellphones while we are talking. You may use your phones during the breaks. If you need to a take a call during the study, we will stop the discussion while you are on the phone.

Before we begin, we'll ask you to review and sign an informed consent form, and tell us about your flight experience on a background questionnaire. Your participation in the study is voluntary and your data will be kept confidential as explained in the consent form.

For your participation in this study, we'd like to give you a $200 gift card. *[Give gift cards now.]*

[Record number of gift card and participant number in data file.]

Do you have any questions?

Session Script

Individual Pilot Review

Take a few minutes to look over the chart by yourself.

Group Pilot Review

Brief the chart with your crewmember(s) as you would normally do. We know in real operations, you would get a specific clearance but for the study, please review all of the different possible clearances you might get for this procedure.

General Discussion with Experimenters

- What elements did you brief with the other crewmember(s) and why?
- What challenges might you anticipate in flying this procedure? In general? For the aircraft type you normally fly?
- What (if anything) struck you as unusual about this procedure?
- What (if anything) struck you as unusual about this chart?
- How would you describe this procedure to another pilot?

General Discussion After All Procedures are Reviewed

FMS

- Are predicted crossing altitudes shown at waypoints where there are no constraints on your FMS? Do you notice or use these altitudes? If yes, how?

Charts

- Is the term "common segment" familiar to you? Where does the common segment begin and end?
- Do you use the communication frequencies on the arrival or departure charts?
- Do you review the climb gradient table on departures? Is it helpful to have on the departure page?
- Do you look at the routing box on arrivals and departures routinely? Did you notice whether the text had more or less information than the graphic depiction?
- How useful is the shaded terrain on approaches? Would you miss the shading if it were not shown?

Operational Use

- If you were cleared on one specific transition of an approach, would you brief the other transitions?
- Have you flown any of these procedures in actual operations? Do you recall any difficulties flying those procedures?
- Explain any issues you might have with use and set up of the automated systems for any of the procedures we reviewed.

Concluding Discussion

1. What features make a procedure difficult?
2. What features make a chart difficult to use?
3. Do you have any thoughts on pilot training for the procedures we reviewed?
4. What would you like people to know about your use of these procedures and charts?

Informed Consent Form

Subjective Complexity of Instrument Procedures

US DOT Volpe Center

I, ________________________________, understand that this study, titled "Subjective Complexity of Instrument Procedures" is being conducted by the Volpe National Transportation Systems Center, United States Department of Transportation. The study is being directed by Dr. Divya Chandra. This research is funded by the Federal Aviation Administration, NextGen Human Factors Division (ANG-C1).

Purpose of Study. The purpose of this study is to understand pilot perceptions of procedure and chart complexity.

S**tudy Procedures.** You and up to two other pilots will review and discuss procedures and charts with researchers. There will be short rest breaks during the study.

Discomfort and Risks. The risks involved in your participation are low and do not exceed those you would experience in a normal office environment.

Benefits to You. Participation provides an opportunity to aid in the development of recommendations for the design of instrument procedures and associated charting. You will be compensated $100 for your participation.

Participant Responsibilities. Please notify Dr. Divya Chandra if you experience any discomfort during the study.

Anonymity and Confidentiality. The information that you provide as a participant is strictly confidential and shall remain anonymous. No Personally Identifiable Information [PII] will be disclosed or released, except as may be required by statute. Situations when PII may be disclosed are discussed in detail in FAA Order 1280.1B "Protecting Personally Identifiable Information [PII]", which is available online at www.faa.gov. A hard copy is available for you to review today.

In the Event of an Injury, we urge that you report any immediate or delayed injuries resulting from the study to Dr. Divya Chandra.

Assurances and Rights of the Participant. Your participation in this study is completely voluntary and confidential. No individual names or identities will be recorded with any data or released in any reports. Only arbitrary numbers are used to identify pilots who provide data. You may terminate your participation in the study at any time.

If you have any questions, please let us know. For further information about this study, please feel free to contact:

Divya Chandra
US DOT Volpe Center, 55 Broadway, Cambridge, MA 02142
617.494.3882
Divya.Chandra@dot.gov

Statement of Consent

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described. I may have a copy of this consent form if I request one.

Participant: ________________________________ Date: ______________

Background Questionnaire

Please write in a response or circle one of the choices. The questions continue on the back.

Past Experience

Total Flight hours (approximate) ___________________

Years of experience with FMS	less than 1	1 to 5	5 to 10	10 to 15	More than 15
Military flight experience?	Yes	No			
Flight instructor experience?	Yes	No			

Recent Experience

1. Are you a check airman or do you provide flight/simulator instruction for your company?

Yes No

2. What is your role on the flight deck?

Captain First Officer Not applicable

3. Rate your familiarity with Jeppesen charts.

1	2	3	4	5	6	7	8	9	10
No familiarity				Some familiarity					High familiarity

4. Rate your familiarity with FAA charts.

1	2	3	4	5	6	7	8	9	10
No familiarity				Some familiarity					High familiarity

5. Rate your comfort with using the FMS.

1	2	3	4	5	6	7	8	9	10
Somewhat Uncomfortable (Still new to it)				Reasonably Comfortable					Very Comfortable (Other pilots ask me for advice)

6. What model/type aircraft do you fly currently? ____________________________

7. Does this model/type aircraft have coupled VNAV?

Yes No

8. Does this model/type aircraft have autothrottle (or autothrust)?

Yes No

9. Type of route flown most often in the past year?

US CONUS Within North America US to South America

Trans-Atlantic Trans-Pacific

10. Are you currently qualified for RNAV (RNP) AR approaches?

Yes No In Training

11. When was the last time you flew an RNAV (RNP) AR procedure in normal operations?

Within 12 months More than 12 months ago Never flown RNP AR in line ops

12. Rate your comfort with RNAV SIDs.

1	2	3	4	5	6	7
Somewhat Uncomfortable			Reasonably Comfortable			Very Comfortable

13. Rate your comfort with RNAV STARs.

1	2	3	4	5	6	7
Somewhat Uncomfortable			Reasonably Comfortable			Very Comfortable

14. Rate your comfort with RNAV (RNP) AR IAPs.

1	2	3	4	5	6	7
Somewhat Uncomfortable			Reasonably Comfortable			Very Comfortable

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Appendix E: Session Summary Rubric

Comments include detailed examples, questions for others, observations, potential follow up questions for other pilots.

Facts

- Number of pilots in session (1, 2, or 3)
- RNP qualified or not
- Type(s) aircraft, VNAV? Auto-throttle?
- European flight experience? Comparison with US procedures?
- Familiar with other crew members?
- Typical routes (duration, international vs. domestic, east coast vs. west vs. mountains)
- Familiarity with procedures in the study. Only include cases where participants are very familiar with the IFP. If they say they went to the airport once, or haven't been there in a long time, or did it in a simulator, or fly to the airport a lot, but not that procedure, none of these count as being familiar with the IFP.
- Significant changes to the charts used in the session (version changes for SLC and BOI)

Observations

- Anything that was unusual about the group relative to other groups
    - Level of knowledge
    - Level of trust in automated systems
    - Emphasis on particular types of operations, such as single-engine procedures
    - Significant differences of opinions between the pilots in the session?

Technique

- Any technique that does not fit under either Briefing or In-Flight

Briefing Techniques

- General briefing techniques
    - For example, using finger to follow path on chart
    - Do they do any math (mental or on paper) as they review the procedure? Or not?
    - Orient/brief a single clearance (any general orientation?)
    - Does each pilot do an individual review or just one?
    - Do the briefings get successively less detailed?
    - What factors would affect their verbal briefing?
    - Typical assumptions? (Conditions that are usually met?)
- Route entry and check before the verbal briefing:
    - Who does what

- Verbal briefing
    - When do they do the arrival/approach briefings
    - What do they focus on when they talk to each other
    - Long/full briefing vs. just the highlights/short
    - Consistency?
    - Do they have significant trouble with the waypoint names
    - Do they mention notes? Some or all? On all types of procedures?
    - Discuss set up of automated systems?
    - Use of the graphic (callouts) and the text box?
    - End with “any questions?” (consistently?)
- For a SID
    - Specific briefing techniques for a SID only
- For a STAR
    - Specific briefing techniques for a STAR only
- Approaches
    - Specific briefing techniques for an Approach only
    - Do they use the briefing strip?
    - Do they mentally compute the descent gradient, at least approximately?

In Flight Techniques

<u>General</u>

- Anything that does not fit under the sections below, related to flying, not briefing.
- For example, do they do mental math as they are flying?
- Do they have the chart displayed/out while they are flying the procedure?

<u>Waypoint Verification</u>

- EDETH question

<u>Lateral Path</u>

- FRDMM question
- [lack of] scale (Edeth question)

<u>Monitoring departure climb out before hitting an altitude (Boston)</u>

- BLZZR question
- What lateral navigation mode is in use? (none, LNAV, HDG?)

<u>Window-altitude constraints (FRDMM)</u>

- FRDMM question

- Does the FMS indicate predicted crossing altitudes? (General Discussion)
- Use of speed brakes

Late routing changes

- No particular question, sometimes comes up regarding FRDMM or general discussion

VNAV Operations

- Do they set up the displays (dual FMS) a particular way?
- Do they use VNAV for descents? Climbs? Short climbs? Long climbs?
- Keep resetting the altitude selector for each constraint, or enter the top altitude?

Nav Database

- General Discussion
- Do they modify the database?
- What is in the database (or not)? (Predicted altitudes for window constraints.)
- Does the database include procedures they are not authorized to fly?

Equipment

- EFBs vs. paper charts?
- Installed EFB (with chart viewer)?
- GPS?
- Autothrottle?
- How the VNAV system works (advisory? Coupled? drag required messages? Wagging?)
- Flight deck displays
- Color conventions
- Single vs. dual FMS?
- FMS manufacturer?
- Flight performance characteristics
- Newer/older?

Typical Operations

- Company policies regarding setup of automated systems
- Company standard operating practices and guides
- Use of autopilot
- Restrictions on EFB use (if available)
- Relationship with Flight Dispatch
- Typical routes? (also in highlights)

General Comments/Questions

- Trust in automated systems?
- Relationship with ATC
- Suggestions for procedure design
- Suggestions for display design

General Procedure Comments

- Experiences at other airports and on other procedures

Chart Comments (Content)

- General suggestions for charting for any of the charts
- Use of EFB for viewing charts
- In the table, categorize element as: Used, Not used, Sometimes Used, No information (not mentioned), Pilots split (different opinions). Some data may come from direct observation of their briefings (what they DID during the study), some may come from discussion with pilots (what they say they normally WOULD DO).

	Use
IFP Title	
Briefing strip for approaches	
Shaded Terrain for approaches	
MSA	
Graphic: Call out boxes for constraints	
Text Route description of SID/STAR (Initial Climb Table or Landing notes)	
ATC Comm frequencies on SID	
ATC Comm frequencies on STAR	
Notes in Briefing Strips	
Lateral Course	
Climb Gradient Table/Takeoff Mins	
Takeoff Obstacles	
ATC Comm frequencies on Approaches	
MOCA/MEA on SID/STAR Transitions	
VOR Cross Radials (on KORRY).	
Latitude/Longitude	
Other?	

Chart Format Comments

Specific to charts with split sections

- Korry inset
- Denver panels
- Boise multi-page

Operational Use (at Specific Airports)

- For example, at Denver, or La Guardia

Specific Procedure Notes

BOS BLZZR

- Any issues with flight performance and constraints?
- Any problem with the 216-heading leader lines?
- Use VNAV or not?
- Comments on noise sensitive procedure or noise abatement procedures?
- Comments on lack of MSA?
- Speed constraint Notes (Boston)

DCA FRDMM

- Do they mispronounce the waypoint names?
- Comparison with Korry? Easier, harder, same?
- Notice the prohibited airspace?
- Notice the naming strategy?
- Did they catch the split at ALWYZ? Any comment?
- Comments on slowing down for the holding pattern?
- Repetition of speed constraints (FRDMM)

BOI RNAV (RNP) Z

- How often do they fly RNP approaches?
- Comments on waypoint spacing?
- Mention the terrain?
- Comment on the altitudes being along the segment rather than on the points?

BOI RNAV (GPS) Y

- Ball note in profile view
- Speed restriction on missed approach hold (not applicable)
- LNAV/VNAV discussion
- Speed constraint on missed hold
- Baro VNAV discussion

SLC EDETH

- Noticed the terrain?
- Noticed the orientation of the briefing strip?
- Noticed the sharpness of the left turn at Sapee?
- Used climb gradient table?
- Discussion of when to speed up after Bucco?

LGA KORRY

- Comparison with FRDMM? Easier, harder, same?
- Flying as RNAV procedure?
- Comments on ball note (for holding speed)?
- Comment on MSA (normally MSA's are only on approaches)?

DEN ILS/Loc

- Noticed the alternate missed approach?

- When to transition to the localizer?

Knowledge

	Notes
Stepped climb and Climb via	EDETH Do they assume that stepped climb procedure just means altitude constraints?
Top Altitude	EDETH What name do they use for the “top” altitude? Consistent?
Terrain vs. MEA altitudes (on SIDs)	EDETH
Descend via	KORRY
RNAV 1 (and RNP)	BLZZR No idea, reasonable guess, some knowledge (generally accurate, but not fully), thorough level of knowledge
Intermediate fix	Boise RNAV (GPS)
Common Route	General Discussion
GNSS Term	General Discussion

Pilot Training

- General Discussion
- What terms do they use (e.g., threats/highlights/gotchas, hold-downs, brackets, step-down)
- Do they use these terms consistently?

What makes a procedure difficult?

- General Discussion

What makes a chart difficult?

- General Discussion

Comments on FAA Charts

- If time available.

Appendix F: Related Issues from the Aeronautical Charting Forum

Issues discussed in the ACF Charting Group (CG) and the ACF Instrument Procedures Group (IPG) that are related to the recommendations in Section 6 are listed below. The first section lists issues that are related to the chart design only, the second section lists issues related to both the IFP and chart and design. Each section is further divided into topic areas. The issues are listed chronologically within each topic area. Specific recommendations from Section 6 are called out as they apply to individual issues.

The CG only handles issues that are related to chart depictions. In cases where there are related IFP design issues, the CG identifies other organizations within the FAA to address those issues. The IPG primarily handles issues related to charts for IAPs, but the CG address all types of terminal charts.

Issue numbers begin with the last two digits of the year in which issue was opened, then the meeting number within the year (01 is in the spring, 02 is in the fall), then the sequential 3-digit issue number. So, for example, issue 10-02-231 was opened in the fall of 2010 and was the 231st issue handled by either the CG or IPG. If the issue is closed, a resolution meeting date is provided. The original meeting minutes are publicly available at http://www.faa.gov/air_traffic/flight_info/aeronav/acf/.

Chart Design

Altitude-Related

04-01-167 Charting of Altitude Constraints on SIDs and STARs

FAA Flight Standards requested that altitude constraints be depicted using a consistent convention across all phases of flight including departures, arrivals and approaches. Three options were presented for FAA charts: over-line/underline convention, vertical profile graphic, or a tabular display. The International Civil Aviation Organization uses the over-line/underline convention, which was selected. Jeppesen will continue to use their text labels, but will consider using the line convention for future data-driven charts. *Closed CG issue in 07-01.*

05-01-174 Top Altitude Note on Standard Instrument Departures (SIDs)

A recommendation was made to develop a standard graphical depiction for the top altitude of a SID. Although the value is available in the text narrative, the narrative is not typically referenced when resuming the procedure after a deviation. There was much discussion about the definition of the top altitude, its source data, and options for depiction. The discussion was transferred to a subcommittee under the IPG and returned to the CG later as 13-01-266. *Closed CG issue in 08-01.*

Related chart recommendation: "Clearly indicate the "top" altitude on SIDs."

07-02-203 "At" and "At or Below" Altitudes

When "at" and "at or below" altitudes were first becoming more common, there was concern that these constraints would be mistaken for the more prevalent "at or above" constraint. The constraints could be depicted with text (Jeppesen charts), the over-line/underline convention (FAA and ICAO charts), or a combination. (See related issue 04-01-167.) A recommendation was made to use the combination text and line convention. Jeppesen is evaluating whether to adopt the line convention. *Closed CG issue 08-01.*

13-01-266 Standard Depiction of Altitude Restrictions on Bottom, Top and Maintain Altitudes on Standard Arrival (STAR) and Standard Instrument Departures (SIDs)

Given the increasing prevalence of SIDs and STARs with altitude constraints, and their use with *climb via* and *descend via* clearances, there was a request to develop a standard depiction of stepped climb/descent and maintain altitude information. The intent is to draw attention to the descent or climb profile and to standardize the location for depicting the lowest/highest authorized altitude. The source of the top/bottom altitude needs to be clear for each procedure, and if there are multiple top/bottom altitudes (for different transitions) these must also be clear. After reviewing prototypes, the group agreed on a format for depicting top altitudes on SIDs and these changes are in progress. Charting of bottom altitudes is still under discussion. This issue references the older 05-01-174. *Closed CG issue 15-02.*

Related chart recommendation: "Clearly indicate the "top" altitude on SIDs."

<u>RF Legs</u>

05-01-176 Charting of Radius to Fix (RF) Leg/Path Terminators

A recommendation was made to establish a charting convention for RF legs because pilots may need to be especially aware of RF legs for procedure compliance. Examples of data about RF legs that may be useful to the pilot are listed (e.g., its presence, radius, length, direction of turn). *Closed CG issue 05-01.*

11-01-239 Radius-to-fix (RF) Turns in Plan View and Profile

The curvature of an RF leg is visible on the plan view of an approach chart, but there is no convention on FAA charts for depicting the direction of the turn on the profile view, which may be confusing to a pilot. Jeppesen indicates turn direction on the profile view with acronyms (RT for right turn and LT for left turn) followed by the word "Arc." Prototypes were presented, but no consensus was reached on the benefit of the turn indication on the profile view versus the additional visual clutter. The issue was withdrawn. *Closed CG issue 11-01.*

<u>Scale</u>

10-02-231 Deletion of 10NM Reference Circle from IAP Plan View

Decided to remove a 10 NM reference circle from the plan view of instrument approaches because it was ambiguous and created confusion. The original purpose of the circle was to indicate scale, but it was not clear to pilots whether or not the circle was the only part drawn to scale, or if it was the containment area of the procedure turn, etc. *Closed CG issue 11-01.*

IFP Design and Chart

<u>Altitude-Related</u>

10-02-233 Removal of ATC Crossing Restrictions (ATC) from STARs

This issue addresses a prior recommendation by the ACF Departure Working Group. The earlier recommendation was to add a notation (ATC) on SIDs and STARs to indicate that an altitude restriction was an Air Traffic requirement as opposed to an obstacle clearance requirement. The goal was to provide the pilot with a minimum safe altitude for obstacle clearance when ATC amends the charted procedure and then clears the aircraft to re-join it while simultaneously canceling charted altitude restrictions. The working group was reconvened to address this new proposal.

After adding the ATC notation on several charts, it was clear the notation added clutter, and that pilots were confused. The navigation database has only one altitude at each waypoint and is not capable of maintaining separate altitudes for terrain clearance and ATC requirements. Pilots did not know which altitude on the chart to use (ATC denoted altitude or MEA) for checking the navigation database. It also was noted that the issue is not applicable to STARs, which have few if any altitude restrictions based on obstacle clearance. And terminal RNAV procedures are all radar monitored, so ATC is responsible for maintain obstacle clearance. STARs are also required to publish MEAs along route segments, which guarantee both obstacle clearance and navigation aid reception; pilots are familiar with these.

It was agreed that the ATC notation should be removed and that a single altitude covering both the obstacle clearance and ATC requirements should be coded in the navigation database. Further meetings within the FAA addressed the detailed requirements and coordination of document changes. These details were then coordinated with the CG. The issue was closed after (a) the issue of describing lost communications procedure was moved to the IPG, and (b) all charts with the ATC notation were updated. *Closed CG issue 14-01.*

11-02-244 Depicting Terrain on Departure Procedures (DPs)

The Navy, Air Force Flight Standards Agency, and National Geo-Spatial Intelligence Agency requested that terrain be depicted on DPs. They cited examples of military airfields overseas, and in the US, with significant terrain near the field and pointed out that terrain is shown for approaches. However, DPs are not drawn to scale whereas instrument approaches are drawn to scale. Criteria would need to be developed to draw terrain on not-to-scale charts. Also, many DPs cover much larger geographic areas than approach charts cover, creating additional issues. This is problem especially for FAA charts, which must be drawn on a standard size page. There was a hope that this issue could be addressed in the future with electronic depictions. The military pointed out that they had the flexibility to draw departure charts with multiple scales and provided concept prototypes, but that was not acceptable to the group. It was also noted that there was no similar request from the civil aviation community, and the military community had other options. *Closed CG issue 12-01.*

Related IFP design and chart recommendation: "Provide data on SIDs and STARs to give pilots a general sense of the terrain in the terminal area."

14-02-280 MEA Usage on SIDs

MEAs are depicted on SIDs, yet are of little or no operational significance. The group agreed that the issue should be corrected in the source data, not the chart. To avoid confusion, guidance was created so that ATC cannot raise MEAs for their own use. *Closed CG issue in 15-02.*

14-02-318 Charting LNAV Engagement Altitudes

Some RNAV SIDs have an altitude that must be reached prior to turning towards the first waypoint on the route. The aircraft must stay on the runway heading until that altitude is reached. The charting of this point is inconsistent and unclear. The purpose of the point is to document the procedure design (specifically, to note when one type of leg ends and the other leg type begins), but its meaning and use is unclear to pilots. Pilots may confuse it with their "LNAV engagement" altitude, which is the altitude at which they are allowed to engage the lateral navigation mode of the FMS, an aircraft- and operator-specific value. It was also unclear to pilots whether to treat this altitude as an actual constraint, in which case it would require a *climb via* clearance for the procedure. Changes were made to FAA Order 8260.46F to delete reference to the LNAV engagement altitude and to provide a variety of design options to ATC facilities for new IFPs. *Closed IPG issue 15-02.*

16-02-310 Inclusion of MSA Info for ODPs, SIDs, and STARs.

This issue was submitted in response to a recommendation made from the current Volpe study to provide data on SIDs and STARs to give pilots a general sense of the terrain in the terminal area. Jeppesen suggests adding MSA information to ODP, SID, and STAR source documents from the FAA so that the MSA can be charted correctly (without using potentially inaccurate MSA information from IAPs in the vicinity of the SID/STAR). MSAs on SIDs and STARs are provided by other countries and are recommended by ICAO Annex 4. There was some discussion about how this would work for STARs that serve multiple airports, but the proposal was supported for SIDs and STARs that serve single airports. The issue will be brought to the ICAO Instrument Flight Procedures Panel. *Related to 11-02-244.* **Open CG issue as of 16-02.**

Related IFP design and chart recommendation: "Provide data on SIDs and STARs to give pilots a general sense of the terrain in the terminal area."

Note-Related

01-01-137 Standardization of Equipment and ATC Procedural Notes

The "Radar Required" note on IAPs may be confusing because it sometimes refers to the need for vectors by Air Traffic to begin an approach and sometimes it refers to having Air Traffic use radar to identify a fix along the approach course, which could also be identified by other means, such as distance measuring equipment. The resolution was to have two different depictions. Where radar is required to determine a fix on an approach course, it is classified as an equipment note and appears in the briefing strip. Where radar is required to enter the procedure from the enroute environment the note will appear in the plan view. The Aeronautical Information Manual will be updated to explain the note to pilots. *Closed CG issue 01-02.*

See also 13-02-312. Equipment Requirement Notes on Instrument Approach Procedures, which quotes the updated sections of the AIM and FAA Order 8260.19E.

Related IFP design and chart recommendation: "Clarify and separate notes based on purpose."

06-01-185 RNAV-1 and RNAV-2 Descriptors for DPs, STARs and Routes

This issue was submitted in order to update chart notes to match planned terms describing different types of RNAV in revised AC 90-100, which will be denoted AC 90-100A. The terms RNAV 1 and RNAV 2 will replace the old terms, Type A and Type B. The definitions of RNAV 1 and RNAV 2 from ICAO standards are provided as a containment area (±1 NM 95% and ±2 NM 95%, respectively). Other documents to be updated include the Aeronautical Information Manual, the Departure Procedures Order, and the STAR Order 7100.9. *Closed CG issue 07-01.*

13-01-270 Step-Down Fix Chart Notes

Current approach charts with step-down fixes inside the FAF contain a note in the profile view that states "*LNAV only." The note is confusing because pilots may not realize that the step-down fix also applies to LNAV/VNAV and circling approaches. The applicability of the note depends on the source of vertical guidance, and pilots may not realize what type of vertical guidance is required. The issue is being coordinated with the United States Instrument Flight Procedures Panel. Resolution may involve changes to the wording of the note, to pilot training, to pilot guidance in the Aeronautical Information Manual, and to FAA Order 8260.19. Changes to the note that are adopted will be implemented as charts are updated for other reasons. ***Open CG issue as of 16-02.***

Related IFP design and chart recommendation: "Clarify and separate notes based on purpose."

13-02-312 Equipment Requirement Notes on Instrument Approach Procedures

A careful read of the FAA AIM indicates that the briefing strip notes and plan view notes are mutually exclusive and both equally apply to the approach. Therefore, the most restrictive note establishes the equipment requirement on the approach. However, this is not clear to the pilot from the approach chart alone, which is what he/she is referencing when flying the approach. Information contained in the two locations may be contradictory, creating unnecessary work. Several examples are provided. The recommendation asks for a single note, with the most restrictive requirements, placement to be specified. A subgroup drafted changes (for the next version of FAA Order 8260.19) to specify wording and placement that take into account consistency with the PBN information box. *Related to 01-01-137.* ***Open IPG issue as of 16-02.***

Related IFP design recommendation: "Minimize and prioritize notes."

Related IFP design and chart recommendations: "Clarify and separate notes based on purpose." And "Reduce overall number of notes."

16-02-328 Complexity of Speed Restriction Notes on SIDs and STARs

This issue was submitted in response to a recommendation made from the current Volpe study to clarify and separate notes based on purpose. The issue paper points out that speed restriction notes for PBN IFPs are becoming more complex. Although chart producers can address depiction and placement issues, they cannot alter the content of the note to make it easier to understand. Speed restrictions with complex and/or conditional forms that apply to an entire procedure are of particular concern because they may be more prone to misinterpretation by pilots. Several example notes from current IFPs are provided. The issue paper requests that FAA criteria and guidance related to the development of speed restriction notes should be updated to improve the simplicity and uniformity of such notes. Existing notes should also be reviewed and their wording should be improved where possible. Notes that require pilot action should be succinct and clearly written for the pilot audience. ***Open IPG issue as of 16-02.***

Related IFP design and chart recommendation: "Clarify and separate notes based on purpose."

Transitions and their Depiction

00-02-130 Confusing Graphical or Textual Feeder Routes

The issue of long feeder routes that extend beyond the plan view of the approach chart is presented, with examples. The depiction of long feeder routes is confusing and difficult to use. Jeppesen has used inset boxes. Some feeder routes are presented textually, which does not help the pilot to visualize the route. The issue was transferred to the ACF TERPS forum. No further discussion is recorded within the CG. *Closed CG issue 00-02.*

Related chart recommendation: "Have a clear graphical connection between sections if the flight path is split between chart sections (or pages/images)."

09-02-220 Multiple Intermediate Segments in Recent RNP AR (SAAAR) IAPs1

The National Business Aviation Association (NBAA) raised the issue of shortened profile views on IAPs with multiple intermediate fixes. IAPs are required to show the profile view for the full intermediate segment, but this is not possible on ones with multiple intermediate segments, such as the Boise RNAV (RNP) Z approach. This is not a clutter issue; it is related to lack of information that would normally be available to the pilot. Boise RNP approaches have obtained waivers from this requirement. NBAA is concerned that many other IAPs will also easily obtain waivers.

The issue was passed on to the PARC Chart Saturation Action Team, which issued its recommendations in March 2010. The Action Team stated that a single intermediate fix results in the simplest charting depiction and that multiple intermediate fixes should be limited to AR procedures, which require authorization. The Action Team recommended against depicting multiple intermediate segments in the profile view of a static chart when multiple intermediate fixes exist. However, data-driven charts may provide additional flexibility to show multiple intermediate segments in the profile view. When there is a single intermediate fix, the entire intermediate segment should be shown in the profile view. *Closed CG issue 10-02.*

Related IFP design recommendations: "Minimize flight path transitions" and "Develop guidance to decide when to separate flight paths into different IFPs or keep a single IFP."

Miscellaneous

11-01-243 Charting Standards for RNP-1 STARs and DPs

Charting standards need to be developed for RNP-1 STARs and departure procedures, in harmonization with the International Civil Aviation Organization. There are many issues, such as the content and clarify of the title, and the ability of the FMS to show the complete procedure title. Initial recommendations were presented to the FAA (9 December 2011) by a PARC Procedure Naming Convention Action team, after which the ACF CG closed the issue (11-02). However, the PARC PBN Procedure Naming and Charting Action Team later reconvened and submitted more complete recommendations to the FAA (23 April 2015). *Closed CG issue 11-02.*

15-01-293 STAR Terminus Point Standardization

The endpoints of STARs are not always clearly connected to the entry points of different approaches. Several examples were provided along with a description of the difficulties this creates for pilots. The bulk of the problem is related to IFP design and criteria. A smaller component has to do with how STAR transitions to the approaches they join are depicted. The CG developed prototype charts showing how the FAA will depict which approaches connect to which STAR transitions. These changes will be coded into the Additional Flight Data section of Form 8260-17.1, which will be in the next version of FAA Order 8260.19. ***Open CG issue as of 16-02.***

15-02-297 Charting of Holds-In-Lieu of Procedure Turns Maximum Holding Altitude

Recommendation from NBAA to chart an "at or below" altitude for hold-in-lieu of procedure turns when a maximum holding altitude is specified in the 8260 forms. The maximum holding altitude would appear in both the plan view and profile view of the IAP, though the final format is yet to be determined. To date, the holding pattern altitude may be shown as “at or above” without a displayed maximum altitude. Pilots and ATC may not be aware that a higher altitude is not acceptable due to terrain in the vicinity. The CG developed a prototype chart and new language for the next version of FAA Order 8260.19 to add the minimum and maximum altitudes for such holding patterns. ***Open CG issue as of 16-02.***

15-01-320 Common Sounding Fix Names

Some fix names in terminal areas create confusion for pilots because they sound similar to nearby fixes or are spelled similar to nearby fixes. Resolving similar fix names can spike workload for crews who are entering late ATC route amendments. Coordination with local ATC facilities has failed to resolve the problematic fix names. With conventional navigation, it was not possible for the aircraft to fly to a fix outside of reception range, so fix names could be reused more readily. But, with area navigation the aircraft can fly, with potentially dangerous consequences (cf., Cali), to any fix in the navigation database. Changes were proposed to FAA Order JO 7400.2 to be more explicit about use of similar waypoint names and AJV coordinated with Dallas and Atlanta to resolve the examples provided in the issue paper. Identifying common sounding fix names currently is a manual process. There are some software tools available but they may not catch all common sounding fix names. Common sounding fix names are typically identified by pilots during actual operations, rather than during the IFP design process. Resolving specific cases can take as long as 18 months. ***Open IPG issue as of 16-02.***

Related IFP design recommendation: “Waypoint names should be pronounceable, short (with few syllables), and, ideally, familiar.”

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