Aeronautical Charts, Procedures, and Complexity

Performance Based Navigation Human Factors Research*

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Funding and Team

- FAA Human Factors Division (ANG-C1)
  - Kathy Abbott & Mark Steinbicker, Technical Sponsors
  - Tom McCloy & Dan Herschler, Program Managers
- Subject Matter Experts
  - FAA, Jeppesen, and many others
- Team Members
  - Becky Grayhem, Andrew Kendra, Alan Midkiff (MIT)
  - Vince Orlando Jr., Caroline Donohoe

Research Requirement

NextGen: Human Factors Guidelines for Advanced Instrument Procedure Design and Use

- Identify issues and develop human factors guidelines for the **design, depiction, usability, and flyability of instrument procedures and associated charts** for inclusion in advisory material and standards for instrument procedures and associated charting.
- The goal is to **produce guidance and standards** that will reduce susceptibility to errors by appropriately qualified pilots.
- The guidelines, recommendations, and data should address known difficulties with use of instrument procedures, and also **address NextGen** instrument procedure requirements.

- Sample links to NextGen Operational Implementation goals (others as well)
  - OI 107103: RNAV SIDS, STARS and Approaches
  - OI 108209: Increase Capacity and Efficiency Using Area Navigation (RNAV) and Required Navigation Performance (RNP)
  - OI 104124 Use Optimized Profile Descent
  - OI 102141 Improved Parallel Runway Operations (RNP Transitions)
  - OI 104122 Integrated Arrival/Departure Airspace Management

Instrument Procedures Project

- Research
  - Gather literature and identify issues
  - Perform analyses and experiments
  - Document and present results

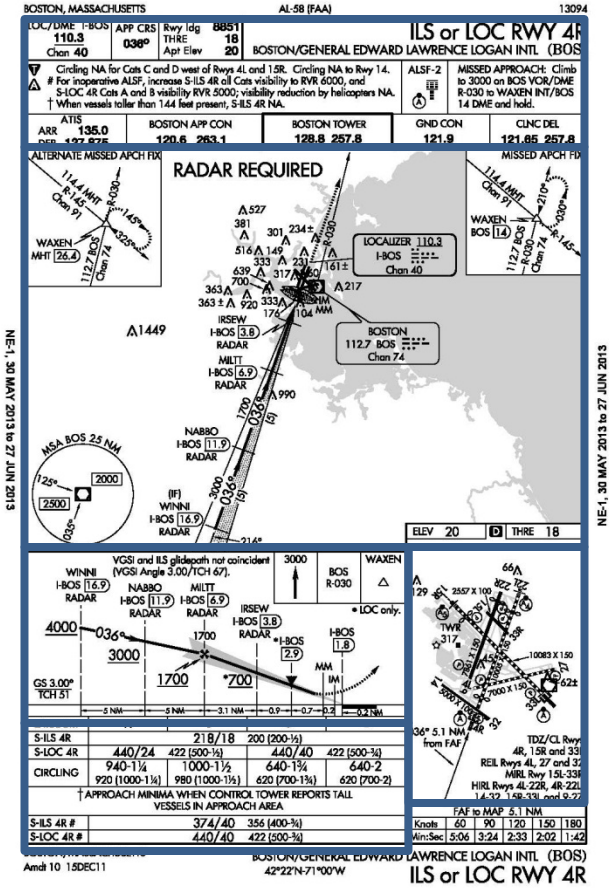
- Provide technical support to FAA human factors research program managers for planning and oversight

- Participate in industry working groups

Overview

- Background
  - Instrument Flight Rules (IFR) Charts and Procedures
  - Performance Based Navigation (PBN)
    - Area navigation (RNAV)
    - Required Navigation Performance (RNP)
- Topics
  - Objective procedure complexity
  - Visual complexity of charts
  - Subjective procedure complexity

IFR Approach Chart Basics



"Briefing strip"

Plan view

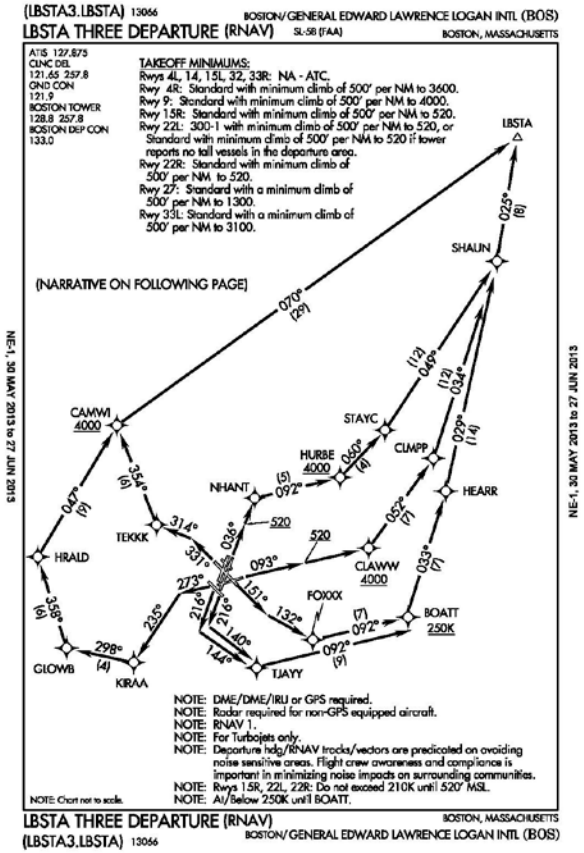
Profile view

Airport sketch (FAA)

Landing Minimums

IFR Arrival and Departure Charts

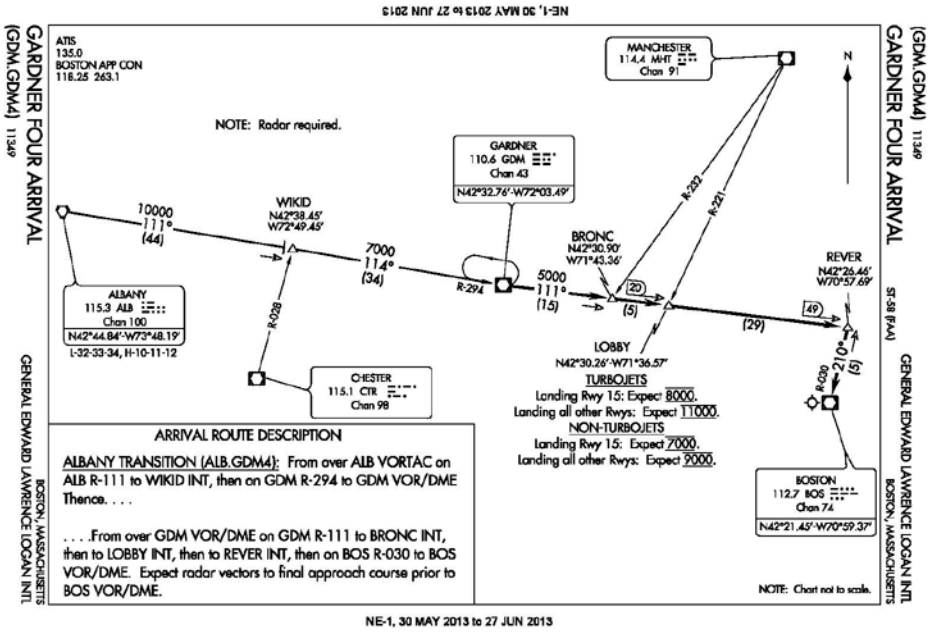
Departure (RNAV SID)



Graphic

Notes

Arrival (Conventional STAR)



Text Route Description

Charts vs. Procedures*

"**Aeronautical chart**" = a chart specifically designed to meet the requirements of air navigation.

"**Instrument approach procedure chart**" = an aeronautical chart designed to provide a graphic presentation of standard instrument approach procedures

"**Standard instrument departure chart**" = an aeronautical chart designed to provide a graphic presentation of standard instrument departure clearances and procedures

- A procedure refers to the information and requirements set by the FAA.

  Procedures are based on criteria (e.g., aircraft performance and terrain clearances).
- A chart is the *depiction* of the procedure.

*Definitions from AC 211-2 (FAA, 1967)

For example…

- When reviewing ASRS reports, it was not possible to tell whether the origin of the issue was in the depiction of the procedure (i.e., the chart's graphic format, layout, etc.) or in the design of the procedure (i.e., the defined paths).
- The easiest way to separate a procedure from a chart is to look at the same procedure in different manufacturer's formats.
  - The procedure is the part that is common across all the different depictions.

Charts, Procedures, and Databases

- The chart is the “human-readable” version of the procedure.
- The navigation database is the computer-friendly format.
- Charts and procedures contain a lot of information that is not in the navigation database.
- Charts support decision making.
  The navigation database does not.

RNAV and RNP Operations

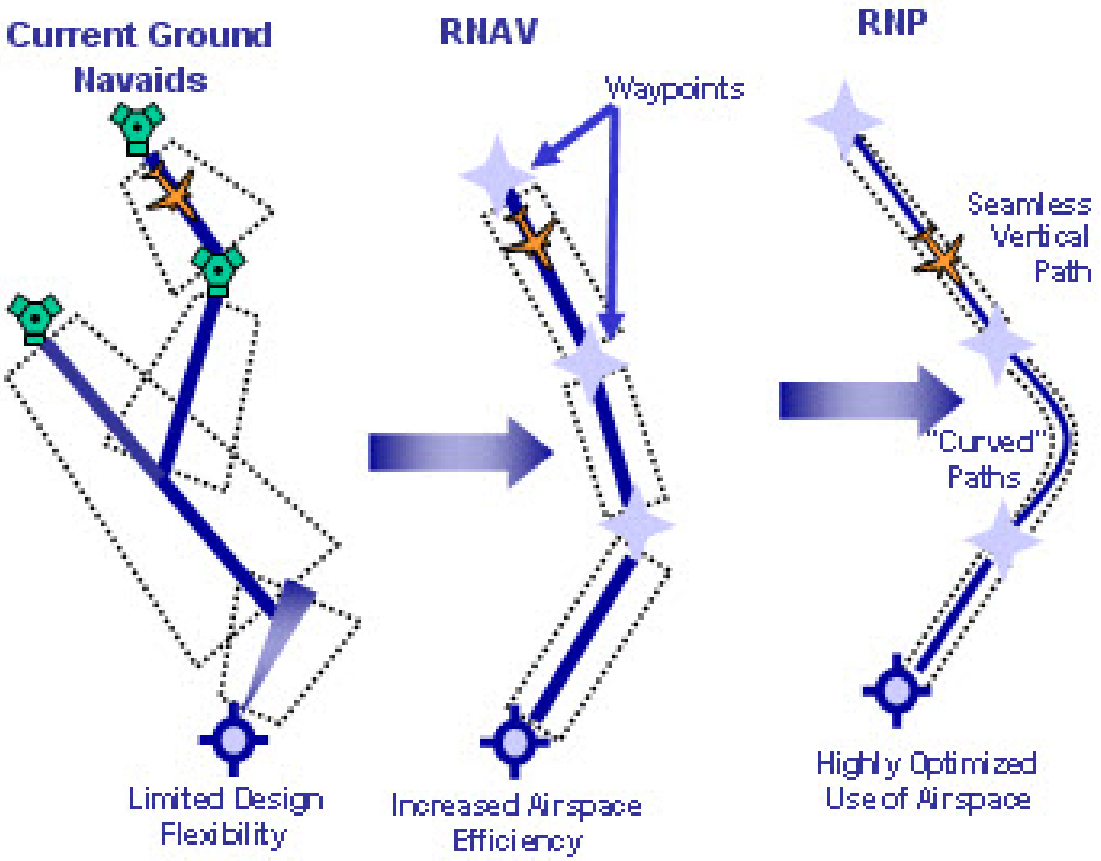


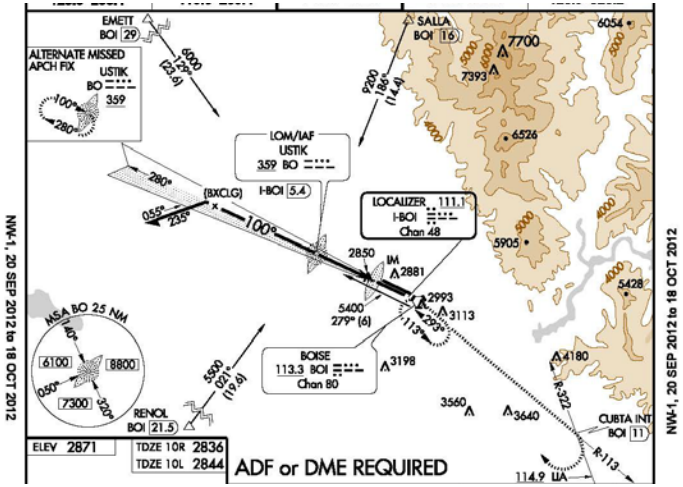
Image from FAA website.

Pilot Training for RNAV and RNP

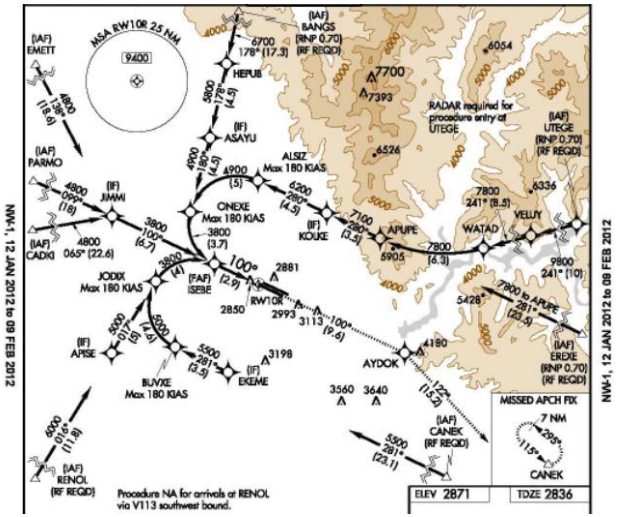
- Familiarity with text and graphical descriptions
- Understand the path and equipage requirements
- Use and understand terminology and ATC phraseology
- Use and understand flight deck automation and alerting interfaces
- Operate RNAV equipment
- Execute contingency procedures in case of RNAV and/or RNP failures

Motivation

- Performance-based navigation brings challenges for human performance
  - More precise routes and constraints
  - More notes and information to process



ILS Runway 10R Boise, Idaho



RNAV (RNP) Runway 10R Boise, Idaho

What is procedure complexity?

Type	Preliminary Description
General Operational Complexity	• Hard to fly and meet all procedure constraints in that aircraft type. • Constant need for the pilot to monitor flight deck systems induces workload, and pilot interventions may be needed. • Procedure instructions are unclear or ambiguous. • Procedure is not compatible with other flight deck systems (e.g., route discontinuities, or ease of dropping waypoints out of the FMS unintentionally).
Vertical Complexity (Energy Management)	• Altitudes or speeds and their constraints are unclear or difficult to meet.
Lateral Complexity	• Headings/turns and their constraints are unclear or difficult to meet.
Visual Complexity	• Procedure depiction (the chart) is unclear or ambiguous. • Procedure depiction is busy. There is a lot of information to filter out or information that could be misinterpreted due to confusion with task-irrelevant information. • Procedure depiction is not compatible with flight deck systems (e.g., in terminology, symbology, or concepts).

Objective Assessment of Procedure Complexity*

- "Problematic" RNAV (RNP) Authorization Required (AR) approaches had significantly
  - More flight paths, 4.1 vs. 1.6
  - More path segments between IAF and runway, 6.33 vs. 3.8
  - More curved (RF) legs, 3.75 vs. 0.4
- "Problematic" RNAV SIDs had significantly
  - More flight paths, 14.4 vs. 5.0
  - Note: Each runway transition denoted a different flight path
- "Problematic" RNAV STARs had significantly
  - More total altitude constraints,† 3.56 vs. 0.67
  - Fewer ATC Expect altitudes, 0.60 vs. 1.83
  - More path segments, 11.4 vs. 8.6

*Part of A. Butchibabu's SM thesis.

†Total altitude constraints is the sum of At or Above, At or Below, Mandatory constraints

So what?

- Objective procedure attributes are of limited utility in determining complexity
  - No big surprises
- Conceptual limitations
  - Operational realism
    - Is this the way that pilots see complexity?
    - How does the analysis apply if the procedure were on a data-driven electronic chart with custom views?
  - Our analysis looked at the procedure, not the chart
    - Doesn't provide any insights about chart visual "clutter"

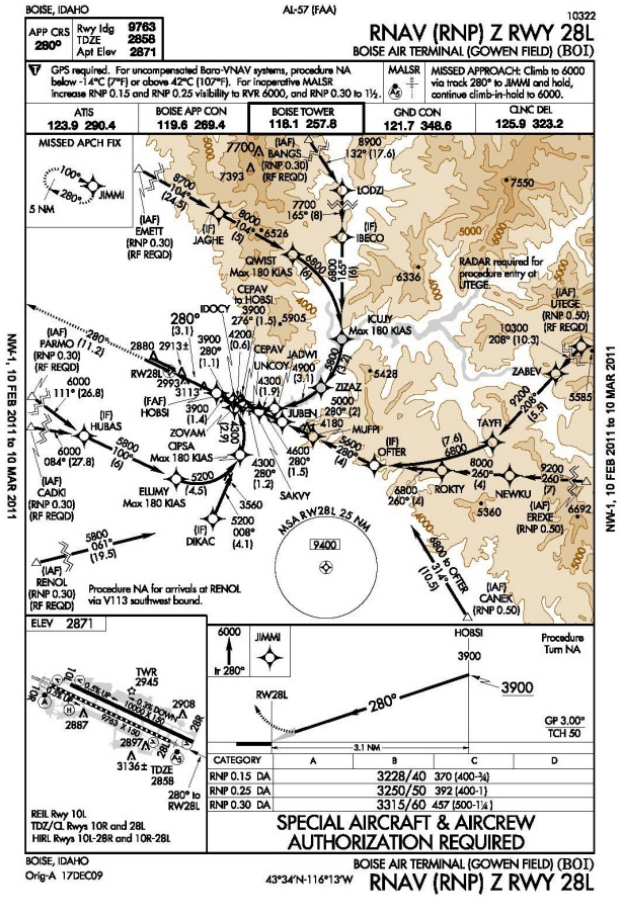
Visual Complexity Study*

- A “first look” at the effects of simplifying RNAV SID and RNAV (RNP) approach charts by separating the paths onto different pages
  - Hypothesis: It is faster to find information from modified charts that show fewer paths
  - Tested the benefits of a “de-cluttering” technique
- Compared time and accuracy of finding answers to specific questions from current and modified charts
  - 47 professional pilots participated
  - Used high-fidelity modified charts developed by FAA AeroNav Products and Jeppesen, shown on a computer monitor
  - Found significant improvements in time to find information using simplified charts

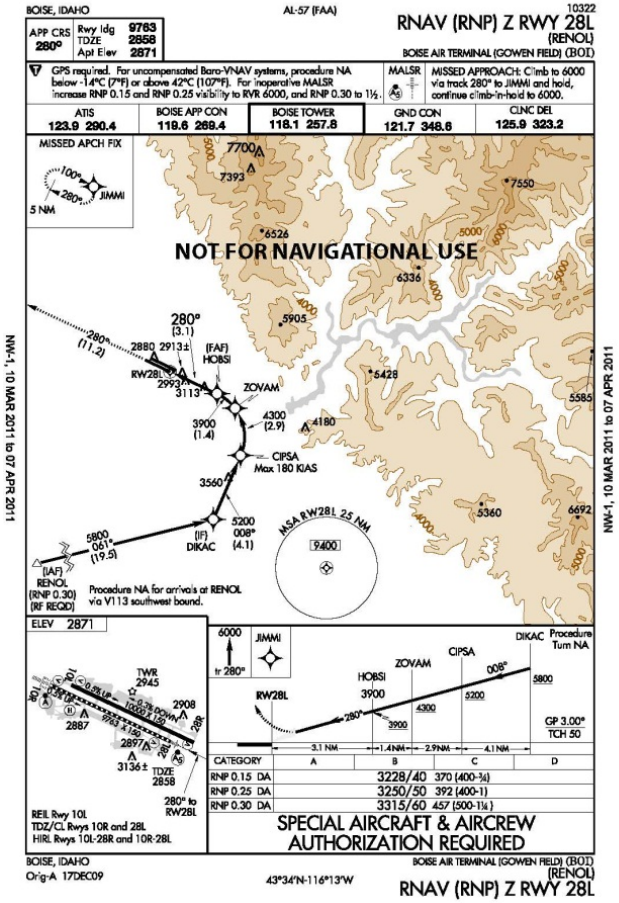
*Part of A. Butchibabu’s SM thesis.

Example Approach Charts

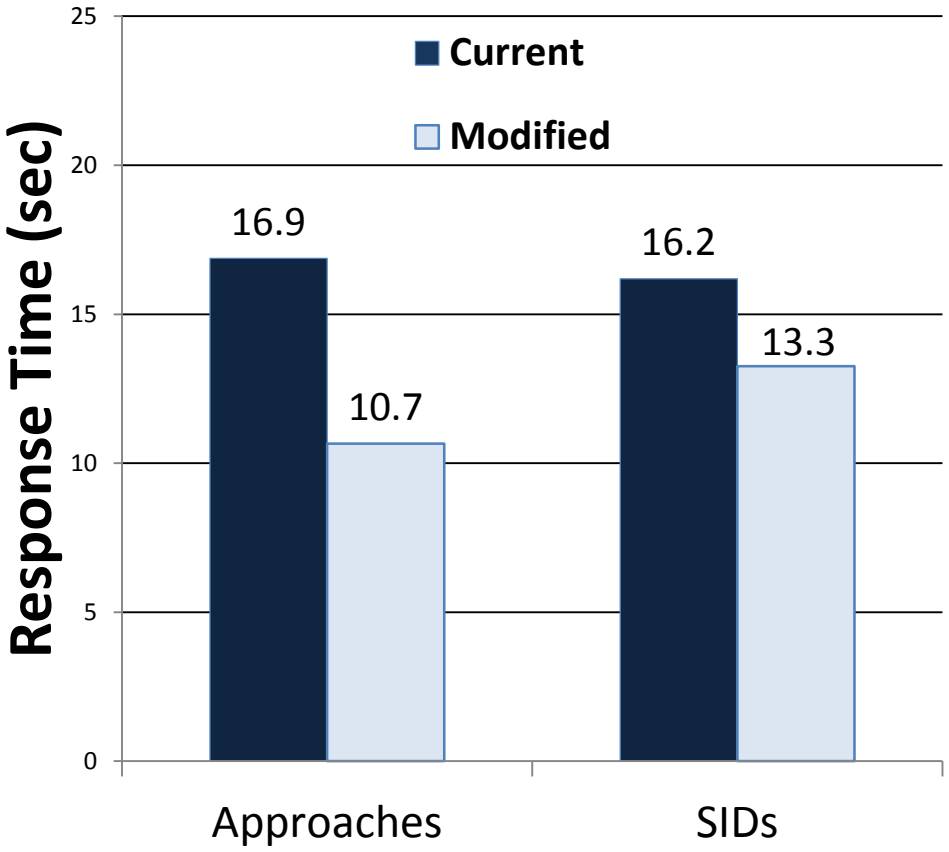
“Current”



“Modified”



Key Results



- Pilots **find information significantly faster** from modified charts
- Determined that pilots use a **serial visual search** strategy
- Good response accuracy overall, but **some questions had more errors than others**, especially with altitude constraints

Planned New Efforts

- Electronic chart usability assessment and recommendations
- Subjective evaluation of procedure complexity
- Procedure design case studies and templates
- Compilation of altitude issues, terms, depictions, concepts, etc.

What We Hope to Learn about Procedure Complexity

- What line pilot perspectives should designers keep in mind as they develop new procedures?
- Are there issues for which pilot training could help to mitigate challenges of new procedure designs?
- What misunderstandings or confusions do pilots have about the procedure designs?
- What procedure design factors overload the pilot and how do pilots deal with that?

Subjective Procedure Complexity Overview of Study Protocol

- Structured interviews with pairs of line pilots (airline & corporate) about procedures they have not seen before
- Office environment, no performance measures
- Paper chart samples
- Interviewers ask questions and take notes
- Categorize and group discussion points

Talking about Procedure Complexity

- Have you seen this type of procedure before?
- What challenges might you anticipate in flying this procedure? In general? For your aircraft type?
- What (if anything) struck you as unusual about this procedure?
- What might be confusing about this procedure?

Research Requirement

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Further Information

- Research plan, technical reports, conference papers

  http://www.volpe.dot.gov/coi/hfrsa/ahf/ip/work.html

- Library

  www.volpe.dot.gov/coi/hfrsa/ahf/ip/library.html

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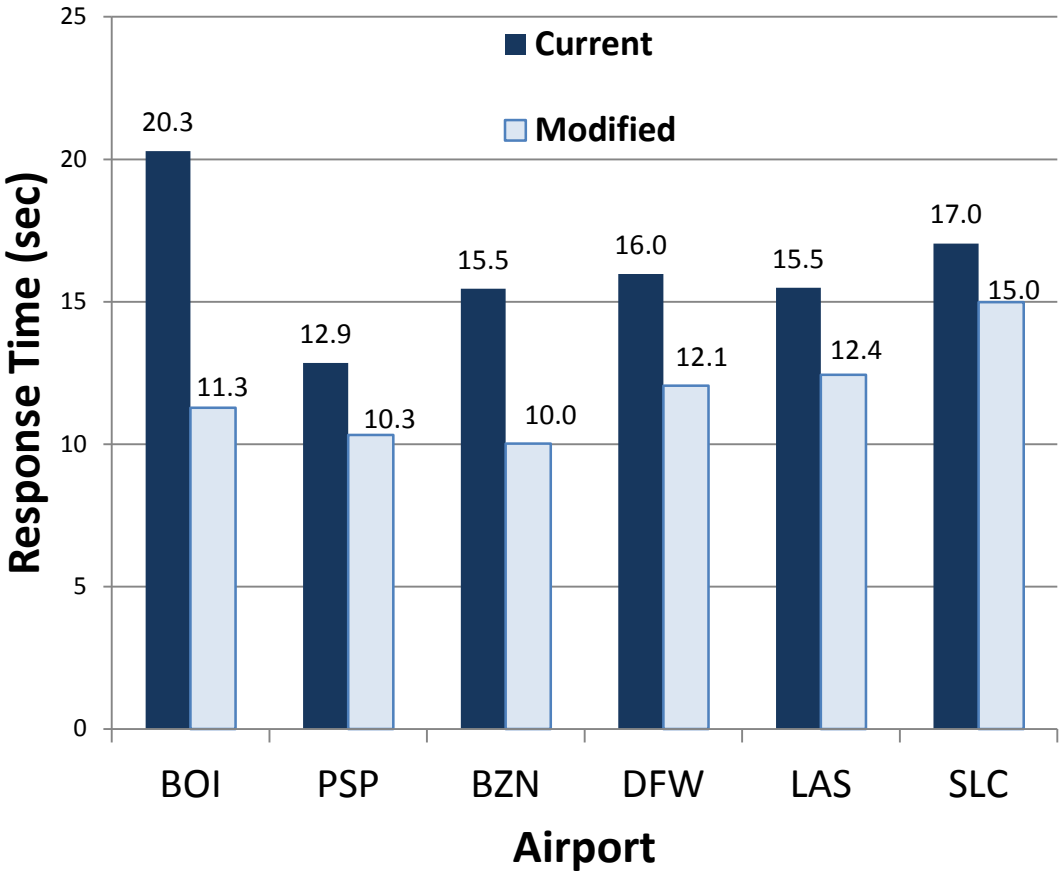
Backup Slides

Objective Assessment of Procedure Complexity*

- Manually recorded procedure attributes
  - e.g., number of segments and distances
- Compared Baseline set to "Problematic" set to identify attributes associated with difficulty of use
  - Problematic by ***our definition***
- Manually recorded attributes for each procedure and flight path within a procedure
  - 63 RNAV (RNP) Approaches
  - 52 RNAV Standard Instrument Departures (SIDs)
  - 54 RNAV Standard Terminal Arrivals (STARs)
  - Used FAA charts current as of 12 January 2012

*Part of A. Butchibabu's SM thesis.

Results By Airport



- All procedures showed benefits of modification
- Some procedures benefitted more from the modification than others
- Could also vary by charting convention
  - For approaches, largest benefit was for FAA BOI
  - For departures, largest benefit was for FAA DFW

*Data includes all trials.

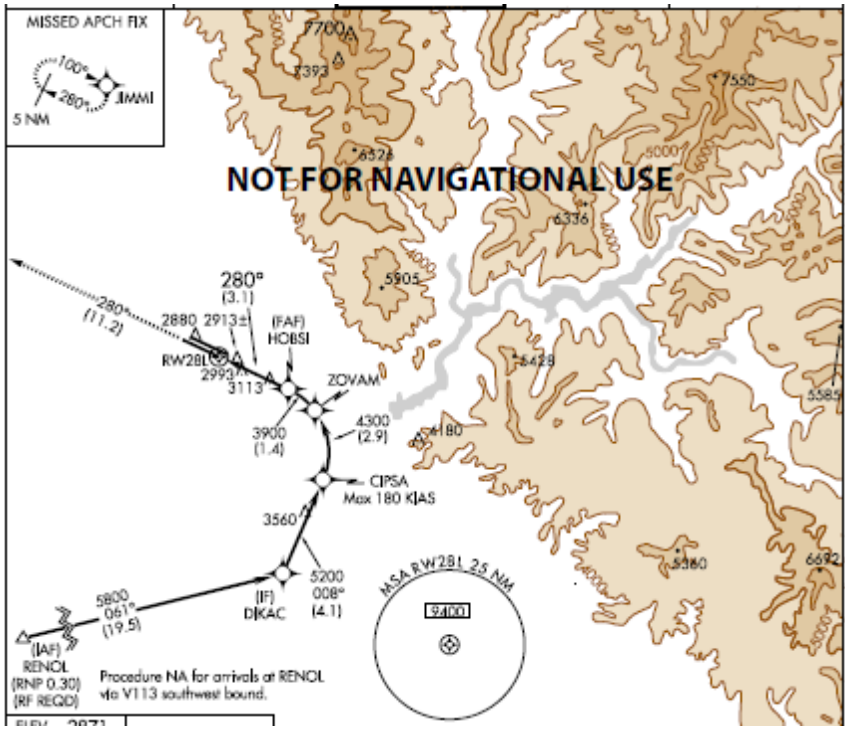
Response Time by Element Count: Analysis Method

- Counted elements on graphical view
  - Different element count for each modified chart image
- Correlated number of elements with average response time for that image

Elements Counted
Minimum En route Altitudes
Headings
Distances
Waypoints
Altitude Restrictions
Speed Restrictions
Notes
Holding Patterns*
Radius-to-fix legs*
Minimum Obstacle Clearance Altitudes**

*Approaches only
** SIDs only

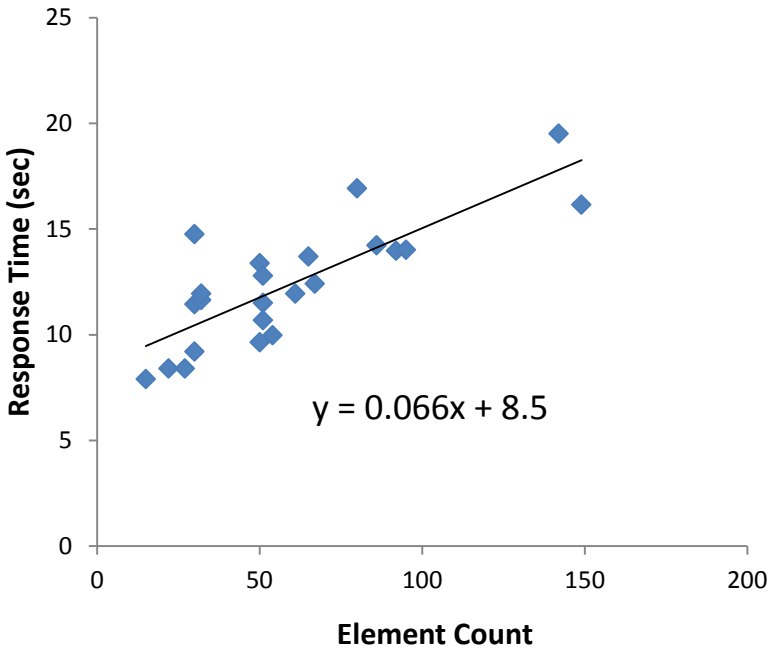
Example Element Count-Approach



Boise Renol Approach Page
2 RF legs
4 MEAs
3 Headings
5 Distances
5 Waypoints
0 Altitude Restrictions
1 Speed Restriction
1 Note
1 Holding Pattern
22 Elements Total

Response Time by Element Count: Results Across Approaches and SIDS

- Removed outliers (response times > 60 sec)
  - 1.8% of approach trials
  - 1.8% of SID trials
  - One bad question from SIDs (1.6%)
- Strong linear relationship between count of elements and response time.
  - Approaches r = **0.87**, r^2 = 0.76
  - SIDs r = **0.88**, r^2 = 0.78
- No correlation with questions from outside the plan view on approaches
- Implication
  - Serial (random) search across the graphical elements
  - Classic visual search



A Debatable Point

- Is it important for the line pilot to comprehend the procedure?
  - Understanding takes effort.
    How much effort? What is gained?
  - Are a better "understanding" and a more flexible mental representation of the procedure useful? Necessary?
- If yes, how can we support the pilot to achieve this goal?
  - Need a balance of understanding and process.
  - Training? Briefing strategies?