TECHNICAL REPORT DOCUMENTATION PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Trajectory Based Operations and the Legacy Flight Deck: Envisioning Design Enhancements for the Flight Crew		5. REPORT DATE January 13, 2012 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Lancaster, J., Riddle, K., Feyereisen, T., Olofinboba, O., Rogers, B., Wyatt, S., He, G., Suddreth, J., & Gannon, A.		8. PERFORMING ORGANIZATION REPORT Click here to enter text.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Honeywell Aerospace Advanced Technology 21111 N. 19th Ave. M/S 2J35A5 Phoenix, AZ 85027		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. DTFAWA-10-A-80031
12. SPONSORING AGENCY NAME AND ADDRESS Federal Aviation Administration Office of NextGen Human Factors Division 800 Independence Ave, SW Washington, DC 20591		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE ANG-C1
15. SUPPLEMENTARY NOTES FAA Technical Point of Contact: Daniel A. Herschler, 202-267-9853		

16. ABSTRACT

This study addresses the gap in scientific information at the intersection of Trajectory-Based Operations (TBO), realistic flight deck – pilot tasking environments, and human performance assessment. The study explored pilot performance, pain points, and system improvements in a human-in-the-loop heuristic evaluation of prototype displays for selected Next Generation Air Transportation System (NextGen) TBO scenarios. Legacy flight deck systems represent the baseline for innovation of TBO concepts. Because "clean sheet" design of both the NAS and the flight deck is seldom possible, designing human-centered "NowGen" interventions for existing systems is a prudent way to evolve toward NextGen. Study Approach: Three legacy and current generation interfaces were adapted using human-centered design heuristics to support Four-dimensional (4D) RTA-TBO, including a Multifunction Control Display Unit (MCDU), an Electronic Flight Bag (EFB), and an integrated Graphical Flight Planning (GFP) system. Seven airline, corporate, and technical pilots evaluated the interfaces in scenarios using different flight phases, weather, and NAS/Air Traffic Control (ATC) conditions. We obtained feedback from pilots on how well the prototyped interfaces supported pilot decision making, how easy they were to learn, their effect on self-reported workload, and the way in which the information was presented. Results: Evaluation participants responded favorably to the MCDU and integrated GFP RTA-prototypes, while the EFB prototype received less favorable feedback. However, the data collected in this study must be considered preliminary, until we have completed more rigorous human factors evaluation and objective pilot performance measurements. The report concludes with our recommendations for further work to develop and refine recommendations for TBO flight deck design requirements and guidance, including refinement and evaluation of EFB design that could support legacy aircraft participation in TBO.

17. KEY WORDS	18. DISTRIBUTION STATEMENT		
Flight deck displays; trajectory based operations; pilot performance in NextGen; electronic flight bag; EFB; 4D trajectory	Distribution unlimited		
19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	185	N/A

Form DOT F 1700.7 (08/72)

Trajectory Based Operations and the Legacy Flight Deck: Envisioning Design Enhancements for the Flight Crew

A Report Detailing Heuristic Evaluation Findings,
Draft Requirements, and Best Practice Guidelines

13 January 2012

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Executive Summary

This study report aims to begin filling the substantial research and development gap at the intersection of Trajectory-Based Operations (TBO), realistic flight deck – pilot tasking environments, and human performance assessment. Lancaster et al. (2011) found that many TBO studies are fixated on demonstrating the operational feasibility of imagined normal TBO procedures, to the exclusion of understanding flight deck human performance with current generation systems. Because "the desired harmony in terms of aircraft and airspace necessarily includes the human element" (p. 8), the present study aimed to understand pilot performance, pain points, and system improvements in a human-in-the-loop heuristic evaluation of prototype displays for selected Next Generation Air Transportation System (NextGen) TBO scenarios.

Equipment designed by engineers—who may not have been trained in interface design—has been surprisingly adequate for pilots of aircraft with legacy systems. Such systems have been deployed in a legacy National Airspace System (NAS), where crews routinely compensate for inelegant design, and substantial margins separate conflicts between efficiency and safety. It is unlikely this approach will continue to work without consequence as these margins are cut, particularly in light of the foundational operational changes planned for NextGen. Adding time pressure (e.g., via Required Time of Arrival (RTA) clearances) will sharpen the conflicts between the crew and the system and may potentially create new clash points.

Still, legacy systems represent the baseline for innovation of TBO concepts. Because "clean sheet" design of both the NAS and the flight deck is seldom possible, designing human-centered "NowGen" interventions for existing systems is a prudent way to evolve toward NextGen.

Study Approach: Three legacy and current generation interfaces were adapted using human-centered design heuristics to support Four-dimensional (4D) RTA-TBO, including a Multifunction Control Display Unit (MCDU), an Electronic Flight Bag (EFB), and an integrated Graphical Flight Planning (GFP) system. Seven airline, corporate, and technical pilots evaluated the interfaces in scenarios using different flight phases, weather, and NAS/Air Traffic Control (ATC) conditions. The study looked at how well the proposed interfaces supported pilot decision making, how easy they were to learn, their effect on self reported workload, and the way in which the information was presented with data captured via a Modified Cooper-Harper rating workload scale, post-scenario questions, and a post-study questionnaire. In general, evaluation participants responded favorably to the MCDU and integrated GFP RTA-prototypes, while the EFB prototype received less favorable feedback. However, the data collected in this study should be considered preliminary and more rigorous human factors evaluation of the concepts while collecting objective pilot performance data is needed.

In a precursor to the evaluation, proposed TBO procedures as outlined by the FAA's list of TBO Operational Improvements (OIs) were assessed and possible human factors and pilot performance issues were identified (Lancaster et al., 2011). This previous work and the evaluation were combined to draft design requirements and best practice guidelines to support TBO operations, which were distilled into categories including Roles and Responsibilities, Information Presentation, Information Content, Control / Input Methods, Procedures and Training, Human Performance, and Workload. Based on the prior analysis and on the results of this study, this report concludes with recommendations for further work to develop and refine recommendations for TBO flight deck design requirements and guidance, including refinement and evaluation of EFB design that could support legacy aircraft participation in TBO.

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Acknowledgments

The authors would like to extend our appreciation to Shawn Doherty, Ryan Howe-Veenstra, Mike Jackson, Dahai Liu, Troy Nichols, and Erik Schmidt who all provided valuable insight in preparing this report. We would also like to thank the pilots who participated in the evaluation.

Acronyms and Abbreviations

4DT	Four-dimensional Trajectory
AMSTAR	Airborne Merging and Spacing for Terminal Arrival Routes
ANSP	Air Navigation Service Provider
AP	Autopilot
AT	Autothrottle
ATAAS	Advanced Terminal Area Approach Spacing
ATC	Air Traffic Control
ATP	Airline Transport Pilot
CDTI	Cockpit Display of Traffic Information
CI	Cost Index
CTA	Controlled Time of Arrival
CTQ	Critical to Quality
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FIM-S	Flight Deck-based Interval Management-Spacing
FL	Flight Level
FMS	Flight Management System
GFP	Graphical Flight Planner
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
HF	Human Factors
HSI	Horizontal Situation Indicator
IAF	Initial Approach Fix

INAV™	Interactive Navigation
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical Guidance
MCDU	Multi-function Control Display Unit
MCH	Modified Cooper-Harper
MCP	Mode Control Panel
MRB	Magnetic Reference Bearing
MSL	Mean Sea Level
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
OI	Operational Improvement
PDA	Paired Dependent Approach
R&D	Research and Development
RF	Radius-to-Fix
RMI	Radio Magnetic Indicator
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTD	Required Time of Departure
SD	Standard Deviation
SOP	Standard Operating Procedure
STAR	Standard Terminal Arrival Route
TBO	Trajectory-Based Operations
TCAS	Traffic Collision Avoidance System
TRACS	Tool for Rapid Advanced Cockpit Simulation
VNAV	Vertical Navigation
VSD	Vertical Situation Display

Introduction

Four-Dimensional (4D) Trajectory Based Operations (TBO) are a cornerstone of the NextGen National Airspace System (NAS) structure and function. TBO specifies and separates the myriad aircraft latitude, longitude, altitude, and temporal paths in a dynamic, variable-demand, variable-supply environment. Contemporary research has demonstrated the basic feasibility of TBO, but human performance assessment of TBOs in realistic flight deck – pilot tasking environments is a significant research and development gap. Crew performance issues, unusual or abnormal operations, and potential problems in the execution of TBO are not well understood.

Trajectory Based Operations that increase efficiency have the obvious potential to adversely impact safety, unless carefully and thoughtfully implemented. For instance, the final dimension in 4D TBO, *time*, is a wholly new implementation for civilian pilots as imagined in the Required Time of Arrival (RTA) concept.

Many pilots still wear watches, some will encounter timed instrument approaches, and a few may be forced to use an Expect Further Clearance (EFC) time as a "fix-time" guide when communications are lost, but committing to a seconds-long arrival window after an hours-long flight is new territory. "When it happens" is largely based on "when everything else happens," and perhaps only the military is well-practiced in rendezvous operations at a precise time and location, and their pilots do so by committing substantial resources to fuel, training, specialized equipment, operational redundancy, and airspace dominance.

Trajectories that fly closer to terrain, weather, traffic, and aircraft limitations obviously increase demands on the crew, necessitating that the flight deck system and TBO procedures are closely aligned with crew capabilities and limitations. At the same time, revolutionary flight deck changes to support new capabilities and better crew interfaces are rare, and are generally possible only on a 7-year new aircraft development schedule. Even so, the "brand new" flight deck is increasingly constrained by common type rating requirements and legacy operating environment compatibility, thus limiting "clean sheet" design. Additionally, draft findings from an FAA study about pilot interaction with automation argue that flight crews are not properly trained for automation in modern cockpits today, without additional challenges of imposing more altitude and time constraints on the trajectory (Abbott Flight Safety Foundation presentation, November 2010, Milan, Italy).

Progression of the flight deck is therefore usually evolutionary, relying on retrofits, upgrades, and repurposing of existing avionics technology. For instance, Required Navigation Performance (RNP) procedures took advantage of existing Flight Management Systems (FMS), autoflight, and displays technologies such as multiple-sensor area navigation (RNAV), Radius-to-Fix (RF) legs, Barometric Vertical Navigation (Baro-VNAV), and course deviation indicators.

Accordingly, there is merit in assessing how well legacy systems are likely to support pilots in TBO procedures, and in determining what display and FMS design improvements may be necessary, sufficient, and possible to support TBO, RTA, and the overall operational safety and efficiency that NextGen requires to be viable. The present research explores the practical, real-world transition between “NowGen,” operating with legacy systems in a changing world, and NextGen, with envisioned routine 4D operations in the NAS.

Purpose, Scope, and Overview

This study report aims to begin filling the substantial R&D gap at the intersection of TBOs, realistic flight deck – pilot tasking environments, and human performance assessment. Succinctly, the purpose of the present research is to assist in determining whether legacy systems can support TBO as envisioned in FAA planning documents. The report also seeks to create understanding on what new technologies and processes must be implemented to meet the need for increased capacity and efficiency while maintaining operational safety.

The work leveraged recent Honeywell efforts investigating TBOs conducted using legacy flight deck automation. This study employed a heuristic evaluation technique as a means to generate subsequent draft system and operating requirements, calling for display and FMS changes that may be needed to adequately support existing TBO concepts of use; particularly, RTA operations.

This report was written during Phase I of an envisioned multi-phase research effort, that at the highest level is exploring how legacy and enhanced systems may best support TBO, and to provide best practice guidelines for designers and design reviewers to assist with the mitigation of crew blunders. In a precursor to the present study, and also during Phase I, proposed TBO procedures as outlined by the FAA’s list of TBO Operational Improvements (OIs) were assessed and possible human factors and pilot performance issues were identified (Lancaster et al., 2011).

Based on this assessment and issues identification, preliminary requirements (detailed herein) for display and FMS enhancements to support RTA were identified to inform the design of legacy and enhanced systems. Display and FMS enhancements based on those requirements, such as the ability to depict aircraft status, targets, and constraints in all 4 dimensions were developed. This study report describes the method and results of the preliminary requirements creation, prototype development, and heuristic evaluation.

Subsequently, a discussion section interprets the results, leading to recommendations for refined draft requirements and proposed best practice guidelines. These are organized by the major human factors and pilot performance issues analyzed and identified in Lancaster et al. (2011), including Roles and Responsibilities, Information Presentation, Information Content, Control / Input Methods, Procedures and Training, Human Performance, and Workload.

This report concludes with a recommended approach to validate and further articulate the draft requirements and proposed best practice guidelines presented herein.

"NowGen" TBO: Today's Precursors to 4D TBO and RTA

It is important to recognize that a number of TBO elements have already been introduced and are evolving in the NAS. Many operational procedures and rules are already in place that can support trajectory based operations – crews are becoming increasingly accustomed to RNAV routing and approaches, and equipment is evolving to support basic navigation requirements, and in some cases, crew interface requirements. Still, there are major human-in-the-loop issues with delivering multiple aircraft at dynamic given altitudes, places, and times, accurately and reliably.

Flight Deck Systems

Area Navigation (RNAV) equipment has been a part of flight decks for many decades, with VLF-OMEGA, INS, VOR-DME, and LORAN-C permitting direct routing, and predating the now widely used Global Positioning System (GPS). While RNAV historically suggested an associated type of equipment, the concept of Required Navigation Performance (RNP), which specifies necessary accuracies by flight phases and procedures, is sensor agnostic (though some procedures specifically preclude certain equipment types with lower accuracies, such as DME-DME). If an aircraft can meet an RNP level, and is authorized to fly RNP approaches, and has an authorized crew, it can execute an RNP approach. RNP has been successfully implemented in both retrofit and forward-fit applications, and can coexist in a utilitarian form on the legacy flight deck.

Control of lateral navigation (LNAV) and vertical navigation (VNAV) have also been available for decades, with the Flight Management System (FMS) flying constraints in both the lateral and vertical. The FMS also facilitates the flying of airspeed constraints, and controls these through the autopilot and autothrottle system. It is important to note that two dimensions (latitude and longitude) are presently controlled on the legacy flight deck with basic reference to the earth. The other two dimensions (altitude and airspeed) are controlled with reference to the airmass. This can create issues when a 4D TBO requires a time, and consequently a speed that is necessarily referenced to a waypoint.

The combination of GPS, LNAV, and VNAV has opened up new capabilities to aircraft. Aircraft so equipped are not constrained by traditional airway Minimum Enroute Altitude (MEA) on enroute planning charts, but rather can use the GNSS RNAV MEA. Further, simply going direct with appropriate off-airway terrain clearance can cut many miles from the flight for these aircraft.

In the terminal environment, even single-engine general aviation aircraft can fly to LNAV/VNAV and LPV minima. These and many other similarly equipped and crewed aircraft can fly a range of RNAV (GPS) approaches that often have arrival points facilitating more direct routing into the terminal area. Highly challenging and curving RNP paths, however, are limited to aircraft and aircrew with special authorization.

While general aviation aircraft tend to enjoy better visualization of integrated flight data (including terrain, ADS-B traffic, and uplink weather), and GPS technology and integration, their autoflight systems are still less capable, albeit less complicated (which may in some cases be a benefit). Autothrottles generally are not available below midsize jets (though Full Authority Digital Engine Control (FADEC) has been deployed on light twin aircraft such as the Diamond DA-42.

Conversely, airlines have many legacy systems that lack terrain awareness beyond a basic Ground Proximity Warning System, and may rely on text transmission of METAR, TAF and other weather products over ACARS. Electronic charting or uplink weather may be possible only via carriage of a tablet computing device, or if the airline can afford it, an EFB installed in whatever real estate remains on the flight deck. It is important to note that as in this example, EFBs are increasingly used in legacy aircraft as a relatively cost-effective way to upgrade display capability when compared to permanent-installation upgrades. Assessing the utility of EFBs in supporting RTA operations is a critical consideration because they represent a potentially valuable tool through which legacy aircraft can participate in TBO without requiring relatively expensive panel-mounted equipment and supporting system upgrades.

In the "best equipped, best served" model, all of this means that it is very difficult to determine who really is the "best equipped," as the aircraft fundamentally are simply "differently" equipped. While one might be legal for RNP based on the ability for the autoflight-nav solution to maintain a given track within ANP within a 95% or 99+% confidence interval, the visualization implementation may be suboptimal from a human-centered systems perspective and require massive amounts of crew training to support safe operation, as well as a herculean effort to accommodate equipment failures and abnormal operations during approach.

New technology could help fit TBO and RTA with the crew's operational heuristic hierarchy. JPDO (2009) envisioned that weather information (e.g., turbulence) would be shared amongst aircraft. Sharing is likely critical to establishing RTAs that are accurate and do not need continuous amendment.

While autothrottle is clearly missing from many general aviation aircraft, this may be a manageable concern in NextGen 4D TBO with proper cueing and digital engine control. More problematic for legacy avionics systems is the fact that autoflight systems use speed references that are airmass-based, and substantial variability still exists in predictions of groundspeed based targets.

Crew Procedures and Operational Hierarchy

Pilots are already cognizant of the need to accurately and precisely control the 3D TBO elements represented in altitude and geographic position. Altitudes are specified many times per flight and are enforced by ATC, and the crew is sensitized to the importance of altitude maintenance regularly via first-hand experience with Reduced Vertical Separation Minima (RVSM), Traffic Collision Avoidance System (TCAS) traffic awareness, and on-board altitude alerting systems like Enhanced Ground Proximity Warning Systems (EGPWS). Additionally, pilots are sensitive to the fact that non-compliance of altitudes, speed or geographic position may result in legal enforcement action that can result in license suspension and/or fines in addition to a fighter jet escort.

Precise latitude – longitude positioning is stressed from the earliest control-performance instrument training using a horizontal situation indicator (HSI) and course deviation indicator (CDI) for performance. Pilots are generally familiar with enroute, terminal, and approach sensitivities used in Global Positioning System (GPS) operations, and for pilots who regularly fly performance-based navigation procedures, Required Navigation Performance (RNP) Procedures and their attendant accuracies.

The control information comes from the power instrument (e.g., N1) while performance is monitored on airspeed. Using the clock as an actual performance instrument, however, is a step beyond most instrument operations. Time is used in other ways that are very specific to a given procedure. For instance, pilots (or the FMS) work to make the timing of the inbound leg of a holding pattern a set value, but do so by measuring the leg time and altering the outbound leg length. Even on a timed approach, the goal is not to cross the missed approach fix at a particular time, but rather to control the distance between the final approach fix (FAF) and the missed approach point (MAP).

Enroute, the temporal dimension is not generally thought of as a constraint, but an outcome. It is critical to recognize that *the best predictor of arrival time is departure time*. This principle sees regular practice in the real world. In Europe, for years, it has been practice for the plane to wait off the runway until under a minute of the scheduled departure time, at which the airplane will be cleared onto the runway for takeoff. The ground delay program is another example of the principle at work.

A well-executed flight starts the day before with an overall plan, evolves further several hours before flight time with refined weather, routing, and a flight plan. Maintenance, preflight and checklist activities are conducted with a sufficient margin prior to planned departure time to carefully manage to this time and allow for an on-time departure. Rushing and compressing activities are not part of this, as they lead to the full range of errors including slips, mistakes, and lapses.

In other words, time is recognized as important. But in civilian operations, it is acknowledged and planned for, then set aside so that proper attention can be paid to executing standard operating procedure. Required Time of Arrival operations are a completely different mindset, potentially placing the ground-based clock at the same level of importance as the airspeed indicator, altimeter, and heading indicator.

It is also important to note that on-time performance generally has the connotation of on-time, or early, such that early arrival is considered a benefit – at least until arriving at an occupied gate. In RTA operations, early arrival is potentially as problematic as late arrival.

Whether consciously or otherwise, passenger crews fly – and will continue flying – according to an operational heuristic hierarchy:

1. Safety
2. Passenger Comfort
3. Operational Efficiency

For TBO and RTA to be successful, they should be designed to accommodate safety and passenger comfort. That is, the RTA must not be arbitrary to the crew. Crews must understand why an RTA is requested, and what is driving it. The rationale behind it needs to be compatible with their operational heuristic hierarchy.

All this said, the ordering of the elements in the philosophy may be able to change during the descent phase, as there is potentially more ability to trade elements in the hierarchy around. For instance, passengers may expect and accept a little more roughness in the descent phase than in the cruise phase. As a further note, the fuel economy task is largely done and is more deterministic by the arrival and descent. As a general note, the positioning of the descent is a potential area of collaboration between pilots and controllers. In current operations, controllers may start descending aircraft prior to a point where the aircraft is most efficient, for instance, a center controller initiating a descent to the terminal area before the aircraft needs to descend.

In addition to understanding these NAS system-level "what is it doing now?" and "why?"questions in the context of their operational heuristics, crews also need to know what is driving their future. Experienced crews are always asking "what is the next thing I'm going to be asked?" Accordingly, at the NAS system-level, provision should be made to reveal the NAS answer to "what is it going to do next?"

There are likely a number of crew expectations and procedures that will complement TBO and RTA. For instance, if there is no associated RTA with a point, crews will expect that the controller will take care of things via radar vectors. Further, pilots will expect that an RTA goes away if they have to deviate around weather because there is no defined path. It is therefore important to recognize that much more than just a point is needed for RTA. In addition, the defined path to get there is critical. In addition to lateral deviations for weather, vertical deviations, such as a climb to FL410 for turbulence can introduce this sort of uncertainty.

In any event, RTA will likely be much more successful in implementation if it is a conversation-with-options rather than a set-in-stone constraint. For instance, for a changing RTA, one exchange might go like this:

- "Center, Citation 789H request (ALT or HDG) deviation, no longer able XYZ at (time)"
- "Citation 789H say new ETA at XYZ?"
- Note that the crew *may not know*, because the storm or altitude change may insert some uncertainty – which points out that the RTA is not just a point, but the route assumption to get to that point. When there is certitude:
- "Center, Citation 789H can make (XYZ) at (ETA)."
- "Citation 789H, cross (XYZ) at (ETA plus time for proper sequencing)"

Operation in the NAS

The current state of trajectory-based operations is reflected in the area navigation, or RNAV route structure and equipment, and the procedures used to position aircraft in arrival, departure, and enroute flows. The compatibility of these elements with aircraft equipment and crew procedures is critical for any successful implementation of 4D TBO.

Per JO 7110.65T, controllers are advised that descent with a speed reduction is very difficult for turbojet aircraft ("I can go down, or I can slow down, but I can't do both"). Accordingly, one task is clearly assigned first, e.g., "reduce speed to 300 knots, then, descend and maintain one four thousand." Prior to descent below 10,000, the aircraft may need to level off and reduce speed to 250 knots (to comply with speed limit regulations), and then continue the descent. Controllers also know to keep speed above 250 knots (or an equivalent mach number) between 10,000 feet and FL280, unless some operational advantage is achievable through a lower speed, and in any case the pilot is expected to advise ATC if unable. Further speed guidance is provided for differing altitudes, distance from the runway, and aircraft category.

For sequencing, "maximum forward speed" and "slowest practical speed" may be specified, with subsequent specific speed assignments as necessary. Removal of the speed restriction via "resume normal speed" does not remove any printed procedural speed restrictions.

Controllers may further use a cross clearance for lateral separation, such as clearing an aircraft to cross a fix *at or before*, or *at or after* a time. Controllers may also specify holding until a particular time, and an altitude change at a particular time. Controllers are aided by a Scheduled Time of Arrival (STA, see Controller-Pilot Glossary), which is a desired time that an aircraft should cross a landing or metering fix, taking into account other traffic and airspace. It displays Traffic Management Advisor (TMA) scheduler results that calculate arrival time considering aircraft performance, spacing, and weather.

While controllers can place a time constraint on a waypoint, it is not believed to be very common. Further, the window for arrival is not widely known. Perhaps more commonly than a crossing restriction based on time (which flight deck automation is generally not set up to handle), controllers can issue a release time which is a departure time restriction used for traffic separation.

Controllers do frequently clear aircraft to fly direct and RNAV routes. Crews operating above FL 450 may fly point-to-point, using facilities and navigation form high altitude enroute charts (Aeronautical Information Manual, 2012). New charting conventions depict more direct routing via RNAV routes (which may be RNAV-2 or RNAV-1 if noted). For instance, in Figure 1, Q1, Q3, Q5 connect to San Francisco terminal area, and Q7, Q9, Q11 connect to Los Angeles terminal area.

In the first iterations of TBO on Q and T routes, care was paid to matching the system to the pilot's real world. On today's planning charts, which may be in paper format or electronically on a personal computer or tablet, compass headings, while not necessary for the GPS system, were thoughtfully plotted on charts, giving a pilot a reference to primary heading data, and aiding situational awareness, specifically, confirmation of orientation.

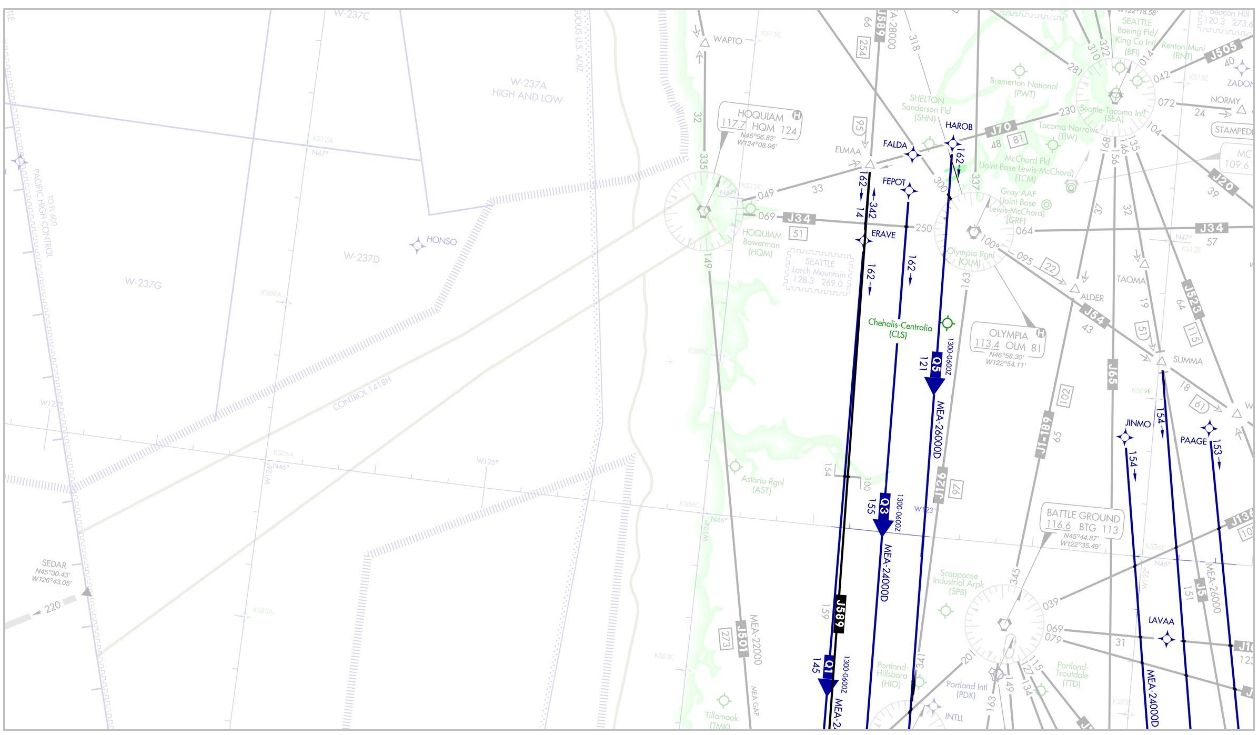

Figure 1. High-Altitude RNAV Q-Routes from Seattle terminal area.

RNAV routes are not always the most direct routes, but rather may be used for most desired traffic flows. For instance, between Boston and Philadelphia, helicopter ("Kopter") routes TK-

502 and TK-504 provide the preferred routing (Figure 2). Low altitude T213, T215, and T217 routes are used to flow traffic around the Cincinnati terminal area (Figure 3).

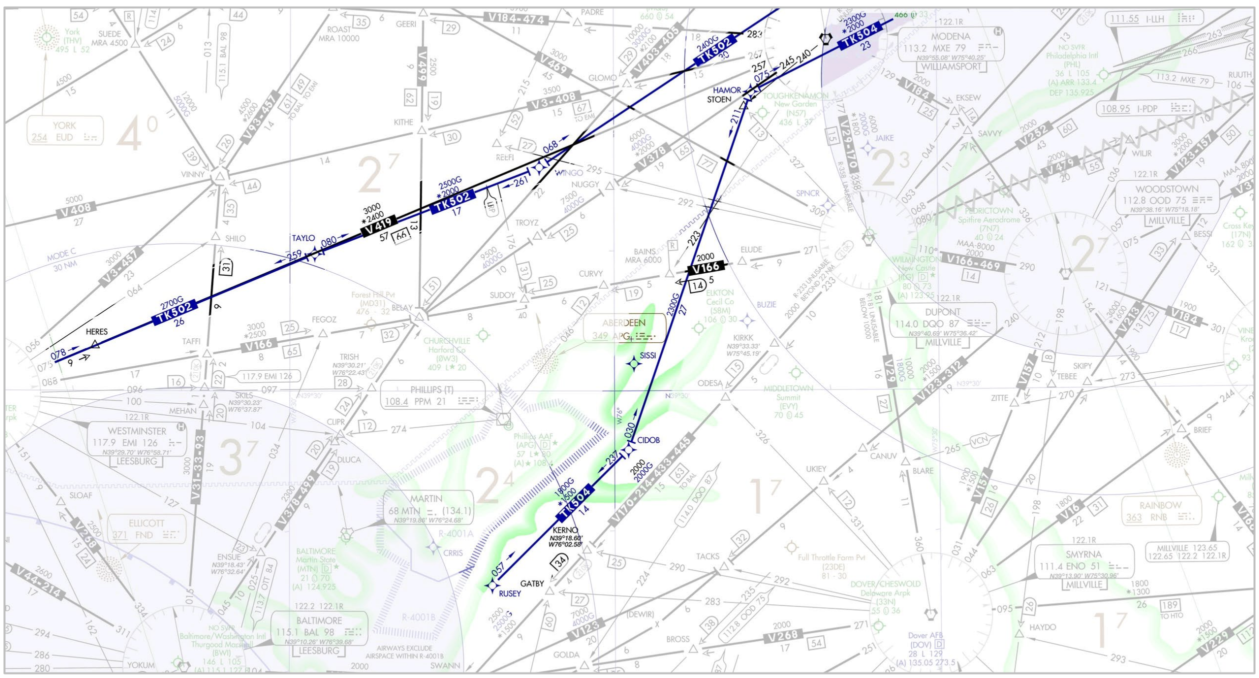

Figure 2. Helicopter RNAV TK-Routes from Boston terminal area to Philadelphia terminal area

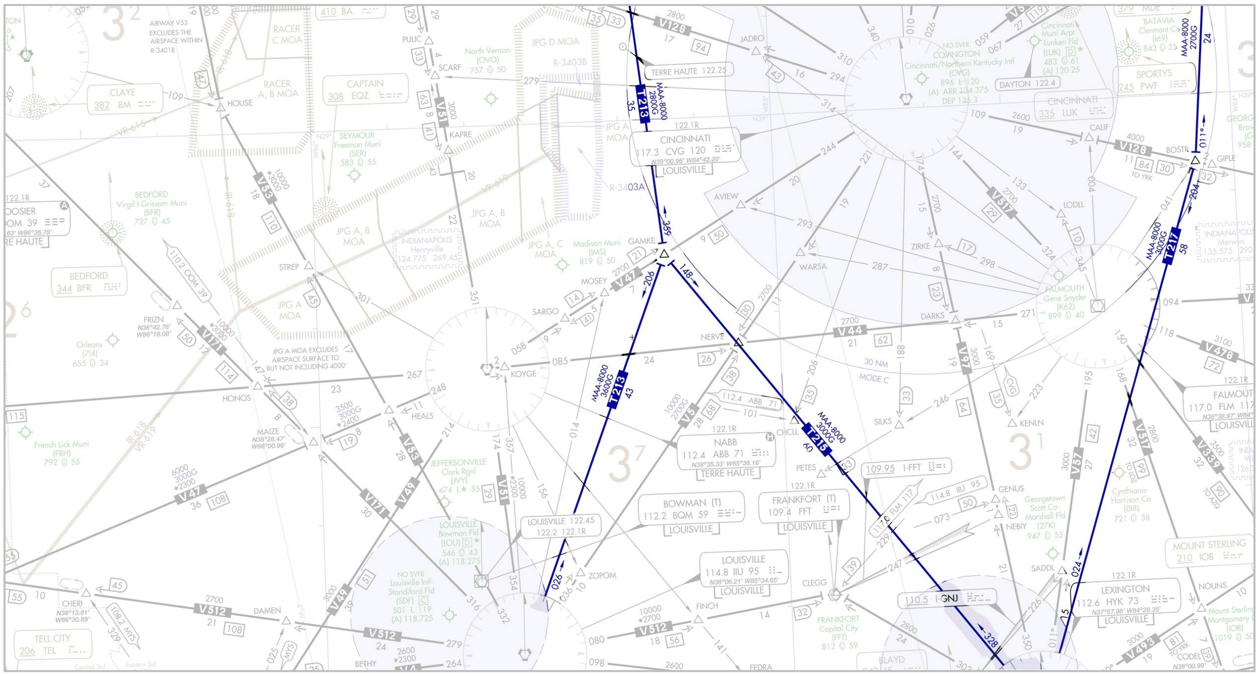

Figure 3. RNAV T-Routes circumnavigating Cincinnati terminal area

RNAV routes can connect to RNAV STARs, and RNAV stars can connect to RNAV approaches. However, whether they do or not varies widely. On a number of RNAV Standard Terminal Arrival Routes (STARs), for instance, we found that it was not possible for the pilot to autonomously connect the arrival to the Initial Approach Fix and the instrument approach. Rather, “expect radar vectors” was commonly printed on the chart (e.g., see first NOTE on the EAGUL Four Arrival chart in Figure 4), presumably defeating a runway end to runway end RNAV clearance. While Honeywell conceptualizes TBO as runway end to runway end, presently it appears that a RTA coming from the TRACON might not deliver the aircraft to a desired runway end.

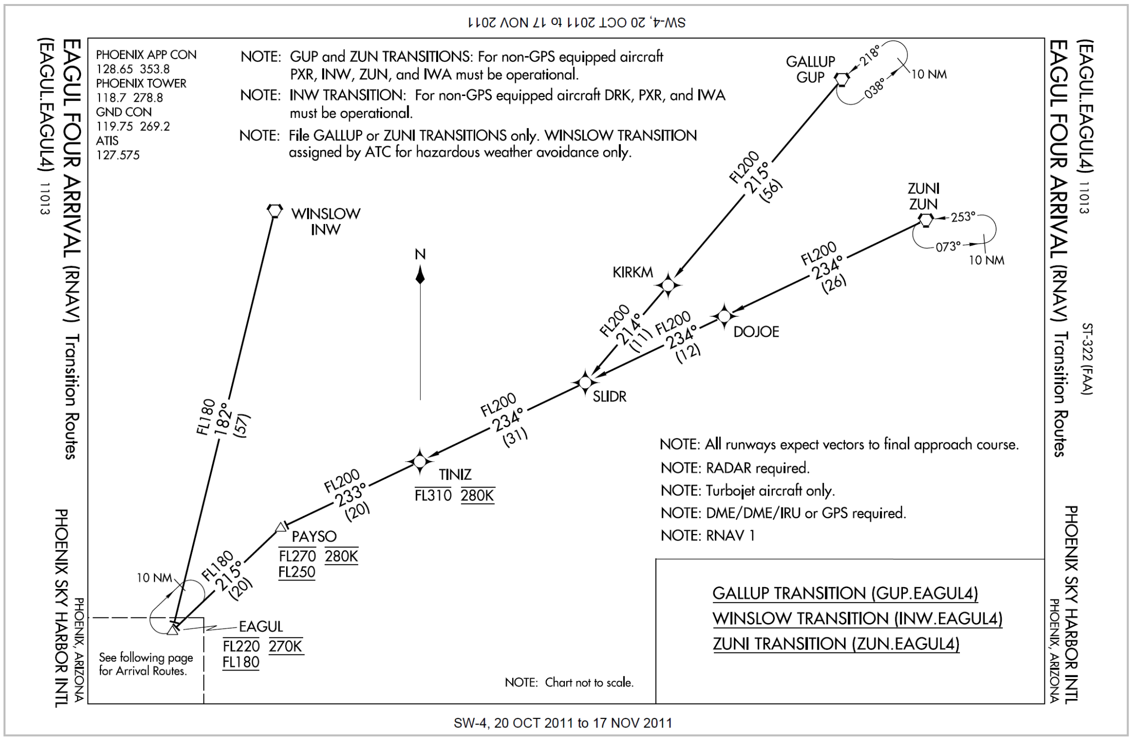

Figure 4. EAGUL Four Arrival to Phoenix Sky Harbor International

At the end of the TBO route is a TBO approach, presumably an RNP approach such as the RNAV (RNP) RWY 21 approach into Scottsdale, AZ (starting many miles away, with the thought in mind all the way to get to the runway end) or the RNAV (RNP) Z RWY 13R approach into Palm Springs, CA (Figure 5). Importantly, the complex curved routes in RNP procedures, which most directly reflect TBO visions, are accessible to only a handful of aircraft due to their limited aircraft applicability, increased equipage and decreased usability (i.e., hand flying an RNP procedure would be a high-workload event).

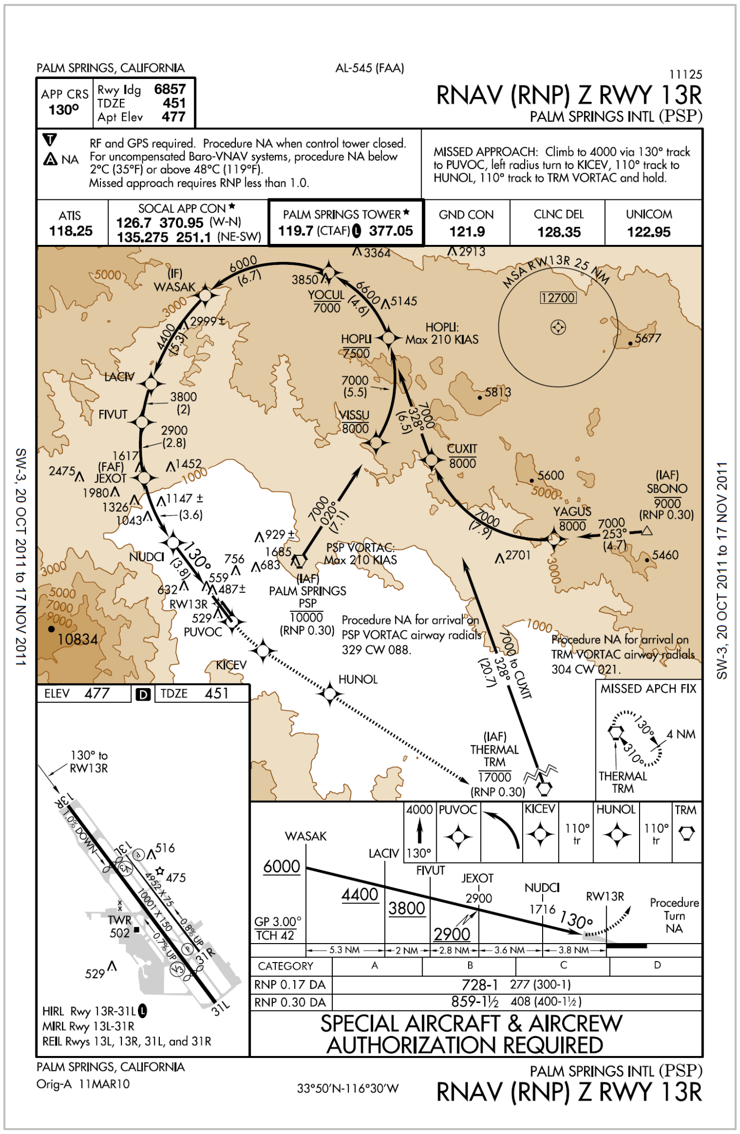

Figure 5. RNAV (RNP) Z Runway 13R Approach into Palm Springs, CA

Building from Honeywell's design and flight operations experience, the literature review and pilot performance issues analysis (Lancaster et al., 2011), Honeywell began formulating and iterating draft requirements. These requirements were focused on display and FMS system components, and sought to facilitate and further direct design work. In 4D TBO, Honeywell recognized that one of the most important backbones for TBO is RTA. Much of the design focus, therefore, was on appropriately adding and integrating RTA into an evolving 3D design solution.

Initial and Iterative Requirements

Based on prior experience developing navigation technologies to support multi-dimensional trajectories and on the aforementioned Phase I output that assessed proposed TBO procedures as outlined in the FAA's TBO OI listing, Honeywell assembled high-level initial requirements for display and FMS enhancements to facilitate pilot decision-making and performance in the context of RTA during TBO. Table 1 outlines the results of the issues assessment, including preliminary requirements, associated preliminary display and FMS prototype features, the rationale for each feature in terms of how they can be expected support those requirements, and link to FAA TBO OIs. These include but are not limited to:

- **Text.** Sometimes spelling it out – literally – makes the most sense. For instance, consider using terms like "early" or "late" even on a graphical display. Displaying "-:08" in isolation could mean 8 seconds late or 8 seconds early, resulting in guessing, potential misunderstanding, and pilot error.

- **Color.** As used with the flight plan and RTA, first minimize the use of color, then carefully assign it to known or clear meanings, and then consistently apply it across the flight deck as part of the overall design philosophy. Never rely solely on color to convey a message.

- **Resolution and Scale.** Consider pilot tasks and decisions to be made during display design. The heuristic evaluation scenarios used +/- 60 seconds (per our FMS expert and associated flight simulator capabilities), but in enroute the RTA tolerance is expected to be 30 seconds and in the terminal area as tight as even 10 seconds. If pilots need to make a decision relative to 10 seconds, then text units in minutes are not appropriate.

- **Hazards.** Pilots will want to make flight plan decisions in the context of weather, traffic, etc. Show these items on the same display to support decision-making.

- **Clutter.** Every widget should have specific, intended function. With weather, traffic, terrain, etc., allow ways to layer and to de-clutter content. Reduce/eliminate unnecessary display markings, edge count, etc.

- **Aesthetics.** A design that looks better, works better. Use clarity, symmetry and unity in design.

- **Integration and interaction.** Reduce pilot burdens to gather, interpret, update and convey data. Support simple and direct interaction.

- **Consistency.** Maintain consistency in details of individual display components across display and displays (font, icons, color use, interaction style).

Table 1. Human factors and pilot performance issues related to RTA, issue categories, preliminary display requirements, prototype feature(s), feature(s) rationale, and relevant FAA TBO OIs (where applicable).

Issue Category	Human Factors/Pilot Performance Issue	Preliminary Display Requirement(s)	Prototype Feature(s)	Prototype Feature(s) Rationale	Relevant FAA TBO OI#
Information Presentation (e.g., format, symbology, location, organization)	The requirements for consistency, accuracy, and timeliness of TBO-related information on flight deck displays have not been established.	• Depict RTA time & current performance	**Graphical Flight Planner (GFP):** RTA data tag & RTA-referenced ownship symbol	Provides RTA performance information via alphanumeric and symbol	101103 104105
			Multifunction Control Display Unit (MCDU): "early – late" text with time	Provides RTA performance information via alphanumeric	
			Electronic Flight Bag (EFB): RTA data tag & RTA "early – late" text with time in pane	Provides RTA performance information via alphanumeric	
	RTA is provided as more of an ancillary function in the FMS requiring several keystrokes to access, and information to monitor RTA is distributed across several MCDU pages. Thus head-down time and workload in accessing and integrating information is problematic.	• Provide clear navigation to MCDU RTA page location • Use MCDU "scratchpad" to alert pilot of an RTA "unable" condition	• Clear prompts to access MCDU RTA page • RTA "unable" appears in MCDU "scratchpad"	• Clear path to access RTA information on single MCDU pg • Awareness of RTA "unable" regardless of current MCDU page	104126

	Numerically signed values used in some FMSs for RTA errors may be difficult to interpret. RTA error depicted as either “early” or “late” would be more intuitive to flight crews.	• Use “early” or “late” text instead of numerically signed values • Include a range of times to meet RTA based on current performance	• RTA information page uses “early” or “late” text • RTA information page includes time range within which RTA can be met	• Supports intuitive awareness of RTA performance • Supports awareness of waypoint arrival times that satisfy RTA constraints	104126
	The amount and type of information depicted for trajectory based operations may cause undue display clutter.	• Provide capability to reduce clutter at pilot’s discretion	**GFP:** map scale range capability	**GFP:** pilots can reduce clutter via display zoom in/out	N/A
			MCDU: dedicated RTA information page	**MCDU:** pilots can monitor RTA information on one page	
			EFB: capability to show/hide screen elements	**EFB:** pilots can show/hide terrain, weather, airspace, traffic	
	It is important to identify display symbology that supports speed modulation, including how pilots can realize their assigned RTAs in situations when their aircraft is off-track and/or if they are ahead of or behind their RTA.	• Provide symbology supporting pilot awareness of ownship speed and its relation to the RTA, and ownship track and its relation to the flight route	**GFP:** RTA- and speed-referenced symbology on or near ownship symbol; ownship track depicted in relation to magenta flight route	**GFP:** pilots can reference the RTA and its relation to ownship speed; pilots can see whether ownship is on- or off-track	102146

	Textual information does not appear to be sufficient to support 4DT – it is expected that a balance will need to be achieved between text and graphical depictions of 4D info.	• Use graphical depictions of RTA information to support textual RTA information where possible/ practical	**GFP:** RTA- and speed-referenced symbology on or near ownship symbol; RTA data tag	**GFP:** use of a graphical depiction along with text helps to explore appropriate balance of RTA information	N/A
Information Content (IC)	Managing aircraft performance to meet the RTA times and locations was more difficult given the lack of feedback. Pilots indicated that they required ground speed, the distance remaining between checkpoints, and throttle up/down indicators information to adequately perform this task, but these information requirements have not been validated.	• Provide speed and distance information between waypoints • Provide information conveying the throttle setting needed to meet the RTA	**GFP:** map scale range capability; RTA- and speed-referenced symbology on or near ownship symbol; RTA data tag	**GFP:** pilots can see the distance to the next waypoint; pilots can determine if ownship speed is to fast or slow to inform throttle setting; RTA data tag includes waypoint name & distance	104126
			MCDU: FPLN page lists waypoints; RTA information page uses “early” or “late” text; scratchpad message if RTA unable	**MCDU:** waypoint awareness supported via FPLN waypoint list; “early” or “late” text informs throttle setting; scratchpad message also informs throttle setting	
			EFB: waypoint list pane depicts waypoints and distance; RTA data tag	**EFB:** pilots can see waypoints along the route and their distance; RTA data tag includes “late” text to inform throttle setting	

Workload (W)	Assessments of RTA have required significant head-down time on the MCDU in order to monitor RTA progress.	• Provide clear navigation to MCDU RTA page location • Use MCDU "scratchpad" to alert pilot of an RTA "unable" condition	• Clear prompts to access MCDU RTA page • RTA "unable" appears in MCDU "scratchpad"	Providing a clear path to access RTA information on single MCDU page and notification of RTA "unable" via "scratchpad" (regardless of current displayed MCDU page) might reduce the need for head-down monitoring of RTA progress	102146

Prototype Development

Prototype development focused on designing display and FMS enhancements such as depiction of aircraft status (e.g., RTA, early, and late), targets and constraints in all 4 dimensions. Prototype development resulted in the creation of display and FMS enhanced prototypes to support migration to 4D TBO.

The objective of prototype development was to support a near-term TBO concept: the Required Time of Arrival (RTA). The RTA represents a time arrival constraint that an aircraft must meet at a particular waypoint along the flight route. Put another way, the RTA is the capability of an aircraft's Flight Management System FMS to "self-deliver" to a specified waypoint at a specified time (Ostwald, 2006). An aircraft's (FMS) is used to control the speed profile to meet the RTA. The RTA may include a specified tolerance or "time window" around the specified time within which the aircraft should cross the waypoint. Generally, the pilot enters the RTA and airborne automation then manages the speed of the aircraft subject to procedure altitude and speed constraints to deliver the aircraft to the point at the desired time or tolerance (Becher, Barker, and Smith, 2005). As a design note, although 30 seconds is a presently contemplated RTA window, a 1-minute notional window was selected from a mid-term feasibility standpoint, based on Honeywell's experience with FMS capabilities and limitations with our prototype software.

Considering the broader utility of the RTA, air navigation service providers (ANSP) exploit the FMS' RTA capability to realize a "controlled time of arrival (CTA)" for an aircraft over a waypoint in the vicinity of an airport. In this context, the RTA represents the tool used by ANSPs to implement CTAs with which to manage and regulate traffic flow into a terminal area. For example, the FMS RTA function can compute a speed schedule to meet a CTA time constraint, potentially at a merge point. As outlined by Ostwald (2006), use of the RTA in NextGen may help reduce the level of ANSP interaction and service required in particular situations, with ANSPs thereby relying instead on the FMS monitoring and actively managing the aircraft in meeting the RTA. An assumption is that one CTA would be issued per flight, perhaps to a waypoint (e.g., at an aircraft's top-of-descent, a metering fix, an arrival fix during descent, or even at the runway threshold) during periods when ANSPs are using their time-based metering capability to manage flow. It should be noted that from a flight deck standpoint, there is no difference between a CTA and an RTA – the CTA is purely an ANSP construct. The RTA in this instance is the control mechanism employed to achieve a CTA that is scheduled by the metering tool (Ostwald, 2006). In NextGen operations wherein a user's preferred trajectory is operative, issuance of an RTA by an ANSP may alter the trajectory for many reasons, such as a need to resolve predicted conflicts, to merge flights from different arrival streams, and to maintain a desired spacing between successive flights. In such cases, which are common during the arrival phase of flight and during periods of heavy traffic, a re-planned 4D trajectory will incorporate the actions needed by the FMS to achieve the RTA. Thus, resolution of these kinds of situations may require actions that were not considered when the initial 4D trajectory was formulated to meet the assigned RTA.

The research team conducted a series of discussions to identify salient display design considerations to support the RTA procedure. An overall display design theme surfaced, which was that the display interactions should be simple in terms of supporting appropriate assessment and monitoring of the RTA procedure, and should not negatively impact workload. The discussions revealed several questions that governed the design philosophy as the iterations were produced to support the theme. The research team thus revisited each of the questions after each of display design iterations to ensure that they were appropriately addressed. These included:

- **Supporting pilots in a multi-task TBO RTA situation.**
  There are several primary tasks pilots must manage for the RTA procedure, including assessing acceptability of the temporal aspect (i.e., what time can I make?), executing the RTA clearance, and monitoring the execution of the clearance. Does the display design support these tasks adequately? What can we do to improve this support?

- **TBO RTA information distribution.**
  If multiple displays are used, is RTA performance information appropriately distributed across the displays? How much or what components of the RTA information should be repeated on each display?

- **TBO RTA information timeliness.**
  Closely related to information distribution is how to support information presentation within an acceptable time frame. Pilots want RTA data and progress information to be presented to them quickly, and do not want to wait (e.g., "hour glass" icon indicating calculation). Does the system produce and present RTA information in a time frame that is useful and acceptable to pilots? What is that timeframe?

- **FMS "thought process" and status.**
  As the FMS calculates, determines, and controls the aircraft's speed profile to meet the RTA within a specified window, pilots want some indication or visibility about this process. For example, when predicted and current winds are different, the pilot may

want to know when the FMS may commence corrections based on that difference. To what extent can the display convey what the FMS may do or is doing to meet the RTA?

- **Critical to Quality (CTQ) elements.**
  The four elements of time performance, fuel savings, environmental impact, and a comfortable ride represent critical qualities for operators, particularly airlines. Does the RTA calculation and associated depictions include attention to these CTQs?

To support the design theme, several display design heuristics were identified and adhered to as the prototype was developed. These were developed and treated as further requirements for display and FMS enhancements to support design of legacy and enhanced systems. Display and FMS enhancements based on these requirements, such as the ability to depict aircraft status (e.g., RTA, early and late), targets and constraints in all 4 dimensions were developed. These requirement heuristics included:

- **Provide multiple viewpoints for 4D trajectory management.**
  The flight plan display will be depicted in lateral (top-down) and vertical (side-on) views. Additional 3D perspective view may be included if a Synthetic Vision display is incorporated into the Primary Flight Display (PFD).

- **Use visual anchor points and consistency.**
  In terms of the details of the views, the use of similar or same colors, icons, font, and other items across display areas will be incorporated to facilitate use and rapid transition between the displays.

- **Minimize display clutter.**
  More information does not necessarily translate to improved performance in terms of display use. The display will not contain so much information that the pilot cannot immediately find information that is needed. Thus, the display philosophy will incorporate, to the extent possible or feasible, a principle of de-cluttering, such as the elimination of unnecessary display markings and other elements that may negatively impact interaction response time. The use of color transparency, cursor hover, or pop-up tags with which to reveal additional information represent examples of avenues through which to realize an uncluttered display. Such techniques help to preserve blank space, which can often serve to highlight or otherwise draw the eye to whatever display elements remain.

- **Use visual momentum graphic techniques.**
  The use of such techniques helps to guide and direct pilot attention to the display.

Examples include the use of shading, morphing, highlighting, low-lighting, transparency, and subtle animation. The goal here is to support pilots in the perception of needed information instead of forcing them to derive the information from a complex or complicated cognitive process.

– **Optimize across displays, and not only on the design of an individual display.** Pilot performance is dependent on understanding at a system level, and not on its individual components. Any design tradeoffs are made in favor of benefitting the entire display and pilot interactions with it instead of on particular display elements or widgets.

– **Primary RTA status information cues are analog.** Analog display information will be used to convey RTA status, as analog information is easier to access quickly and supports streamlined understanding of trends.

The design team identified three display conditions to depict RTA information: 1) A revised multifunction control display unit (MCDU), 2) a graphical flight planner (GFP) consisting of integrated RTA forward field-of-view displays, and 3) an electronic flight bag (EFB). The MCDU represents legacy equipage that has been revised to support RTA functionality. In this vein, the display can be considered a mid-term solution to support RTA operations that may not be as expensive for operators in terms of an upgrade as would be new “glass”, but with the associated potential downside that it is text only/without a graphical component. The GFP represents an example of panel-mounted modern equipage to support RTA operations, and the EFB represents an effort to provide a modern equipage solution for RTA operations designed as a portable electronic device inclusive of electronic approach charts (i.e., Class 2, Type B); for example, located in an outboard position on the flight deck. Both the GFP and the EFB were subjected to iterative design by the research team. The iterative process for each display is described below.

Graphical Flight Planner

Development of the GFP encompassed several iterations. The GFP was designed as an integrated navigation display solution to support RTA operations as a near-to-mid-term concept. The primary goal for the GFP is to create intuitive functionality and interaction to the flight crew as they monitor and manage RTA performance. The initial design for the GFP is depicted in Figure 6.

Figure 6. First GFP design iteration.

In Figure 6, the RTA elements of the display are indicated by the yellow lines (or "bands"), circles, arrows, and green lines. The yellow bands represent what ownship can meet in terms of an RTA (i.e., not be "early" or "late"), with the arrows on the bands indicating whether a throttle input to accelerate ownship (i.e., the "up" arrows) or whether reducing throttle to decelerate ownship (i.e., the "down" arrows) would correct a "late" or an "early" RTA condition, respectively. The circles on the yellow bands represent the predicted aircraft location based on current settings. The size of the circle changes based on the level of uncertainty – the closer to the RTA waypoint, the smaller the circle size becomes (and the converse of this). Along with the circle's size, the circle will itself "move up" the line to encircle the RTA waypoint as progress toward the waypoint is made. Additionally, when operating a modern FMS, a Cost Index (CI) setting is required. The CI generally includes the cost of time (e.g., crew, time-based maintenance) and the cost of fuel. A CI of "0" can be defined to optimize the flight for minimum fuel burn, and in most situations, the cost of time is a factor and a CI greater than "0" results in the lowest total cost of operation. For example, airlines often establish a CI using proprietary information, such as company-specific crew and operating cost factors. Thus, the green lines in Figure 6 indicate a preferred CI "potential". Considering the three depictions of these elements in Figure 6, the top depiction indicates that ownship is behind schedule – if the throttle were engaged to get back on schedule, the yellow circle would move up the yellow line to indicate an on-schedule condition. The middle depiction in Figure 6 indicates that ownship is on schedule; there is no "up" or "down" arrow to suggest throttle input or reduction is required to meet the assigned RTA. The lower depiction in Figure 6 indicates that ownship is ahead of schedule, and that reducing throttle input would help to get ownship back on schedule to meet the assigned RTA. Note that the circle also appears on the Vertical Situation Display (VSD) below the lateral display; Figure 6 depicts ownship is currently within the RTA time constraint and thus matches the middle depiction in the lateral display.

The research team evaluated the initial design and found more questions than answers. In particular, there was concern regarding the intended function of the various “widgets” in the design, and how the team would expect pilots to use them. Additionally, the use of color was problematic, as there are particular meanings associated with the prominent use of yellow and green on flight displays. The research team then solicited other design ideas.

The section iteration of the GFP symbology is depicted in Figure 7. In the Figure, distance is represented spatially, wherein the color orange indicates ownship’s potential position in terms of the RTA based on current performance, the color green indicates ANSP-imposed RTA time constraints (e.g., 30 seconds), and with the circle indicating ownship’s predicted position. Thus, Figure 7 indicates ownship’s progress to the REDDD waypoint and to the subsequent waypoint with an RTA (GRANJ). In the depiction, ownship is ahead of the RTA by approximately 26 seconds, and based on current settings, ownship can be expected to be early at the next two waypoints as well (i.e., GRANJ by 1:03, KCMI by 1:51). Progress to the next waypoint is depicted by a “countdown” digital display at top left.

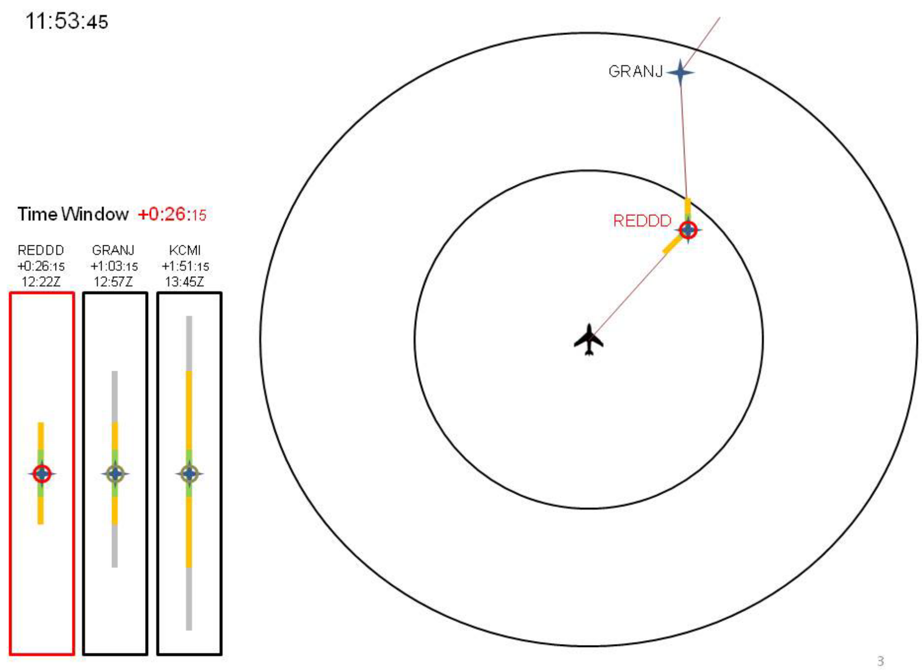

Figure 7. Second GFP design iteration.

The research team reviewed the second iteration and concluded that the display was too cluttered and had color problems (e.g., use of red, amber). Additionally, it was unclear whether the reference is to ownship or to the RTA waypoint, and how the display would compensate if the RTA waypoint were located outside of the selected range.

The third iteration of the GFP maintained the idea of display scale identified in the second iteration. It was thought that a user-selected range around ownship would help to associate ownship with the RTA waypoint. As a RTA is an operation that is temporal-based, the research team reviewed other time-based NextGen-type operations for insight into symbology. One research effort conducted by the Flight Deck Research Group at NASA Ames Research Center resulted in the 3D Cockpit Display of Traffic Information (CDTI). The 3D CDTI was designed to support a host of NextGen concepts, including conflict detection, alerting, and resolution, route analysis, and Paired Dependent Approach (PDA) spacing (NASA, 2004). For the latter operation, the display included monitoring symbology supporting pilot detection of spacing problems in the conduct of in-trail following during approach to landing, and the associated possibility of pilot intervention. The display included a PDA "spacing box" (see Figure 8), which included bracketing symbology and colors representing various temporal spacing conditions.

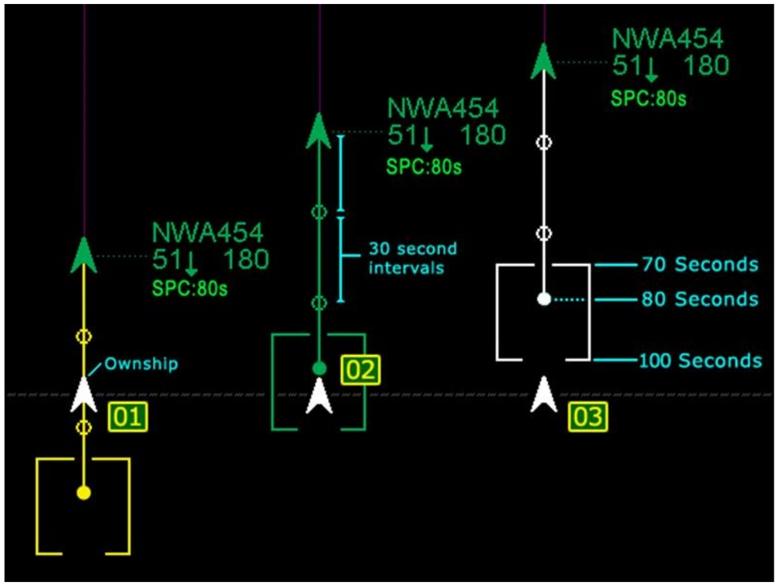

Figure 8. Spacing monitoring on the NASA Prototype CDTI.

Thus, the research team decided to apply similar bracketing to the GFP (see Figure 9). In this design, the "bracket" symbology depicts RTA performance with respect to a selected waypoint that has an RTA constraint, with the bracket positioned on the flight path in both lateral and vertical views of the display. When ownship is "within" the bracket, ownship is within RTA tolerance. Note the display scale in Figure 9, with the range currently set to 450 nm.

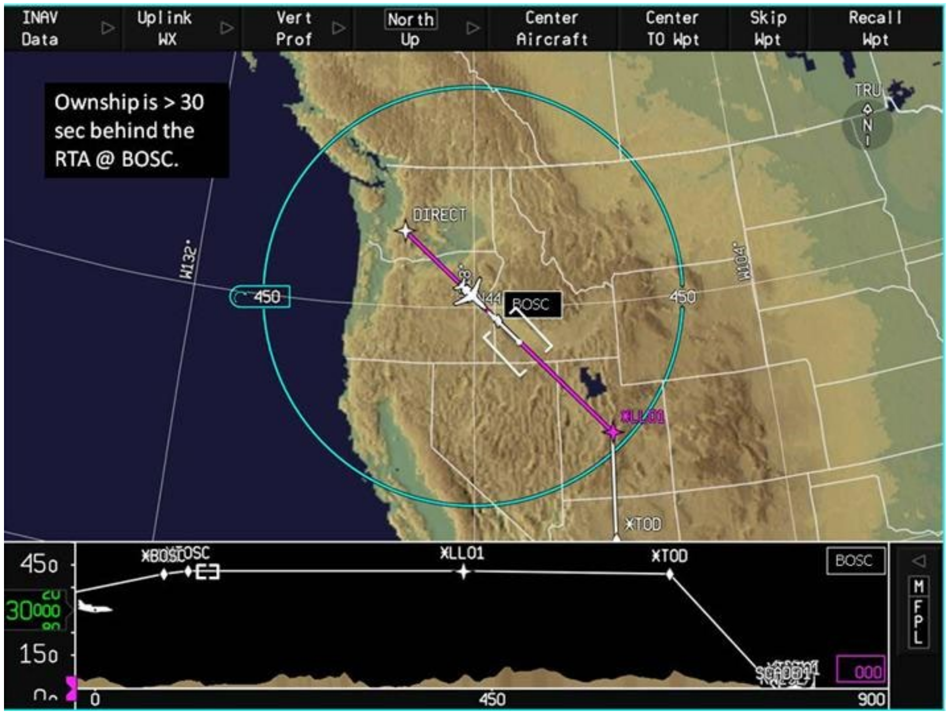

Figure 9. Third GFP design iteration.

In keeping with the NASA display, a series of “dots” were used to correspond to a temporal value (e.g., 30 seconds; three dots equals ownship is 90 seconds “late” in terms of RTA tolerance). The research team reviewed the concept and decided that the brackets were too large, and would be especially problematic in terms of display clutter at higher magnifications and in regions with considerably increased waypoints and other symbology.

The fourth iteration of the GFP resulted from further literature review of symbology supporting a temporal operation. In this case, the operation remained that of in-trail spacing; in particular, symbology supporting the Advanced Terminal Area Approach Spacing (ATAAS) concept and its subsequent iteration, Airborne Merging and Spacing for Terminal Arrival Routes (AMSTAR), which was developed by NASA Langley Research Center (LaRC) (Barmore, Abbott, and Krishnamurthy, 2004). The two concepts depicted spacing information on the navigation display, and included a “spacing position indicator”, which can be described as an inverted ‘V’ or “picnic table” (see Figure 10). When ownship is properly spaced, the indicator fits exactly over the apex of the ownship symbol. Simulation and flight trials with the symbology have been conducted which revealed that pilots did not report any objections or issues with the symbol (Oseguera-Lohr, Lohr, Abbott, and Eischied, 2002). NASA LaRC is working on a third generation of the display, which will maintain the “picnic table” symbology (RTCA, 2010). Similar research efforts including the “picnic table” symbol depicted on displays have been conducted, including a series of EFB investigations by MITRE to assess Flight Deck-based

Interval Management-Spacing (FIM-S) performance (e.g., Bone, Penhallegon, and Stassen, 2008; see Figure 11).

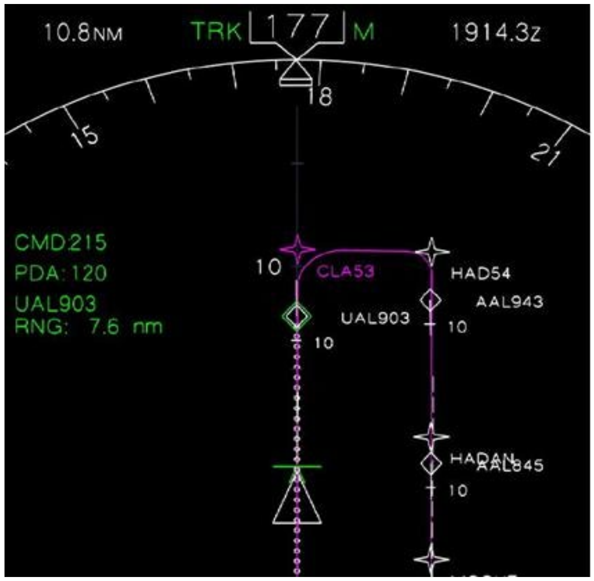

Figure 10. AMSTAR incorporating the "picnic table" symbology for temporal spacing maintenance (from Oseguera-Lohr et al., 2002, pgs. 4, 5).

Figure 11. MITRE CDTI on an EFB incorporating the "picnic table" symbology for temporal spacing maintenance (from RTCA 2010, p. 209).

The research team thus decided to utilize the “picnic table” symbology to support pilot RTA maintenance, and additionally made several other changes to the GFP to result in the final design that would undergo heuristic evaluation (see Figure 12). The additions are as follows:

- The “legs” of the picnic table point toward ownship when the RTA tolerance is either “early” or “late”, whereas when RTA tolerance is “on time”, the legs disappear and the “table” portion is positioned at the middle of the ownship icon.
- An “RTA tag”, which includes information regarding FMS, the operative RTA waypoint, and current airspeed.
- The operative RTA waypoint was surrounded by a green color of the same hue as the picnic table and the RTA information in the RTA tag.
- A time scale on the edge of the scale circle, which indicates the time required for ownship to travel from the edge of the circle to the center of the circle.
- Addition of the RTA waypoint to the waypoint list of the flight plan. The waypoint is shaded in green, and includes waypoint performance information and the estimated time of arrival (ETA) at that waypoint in cyan.

Figure 12. GFP fourth iteration, inclusive of "picnic table" depicting an on-time RTA tolerance, RTA data tag, green RTA waypoint, and RTA waypoint information added to the flight plan waypoint list.

Electronic Flight Bag

As mentioned earlier, assessment of the EFB in support of TBO was particularly important due to its potential as a relatively cost-effective upgrade to legacy-equipped aircraft, allowing a much wider range of aircraft to participate in TBO. The EFB was designed as a touch screen with the initial plan being to include display of traffic, runways/taxiways, terminal charts, terrain, weather, airspace, waypoints, and routes. The first iteration of the EFB included a main graphical/ trajectory display in both lateral and vertical formats (see Figure 13). The top pane depicts ownship's lateral trajectory. Depending on the view selected in the EFB display menu (see below), the lateral view will depict ownship's current trajectory or its alternate trajectory. The EFB display includes depiction of airports, airspace, and waypoints that are part of the trajectory. The airspace in the lateral view of the EFB display was designed to be dynamic in that it displays terminal area airspace at both the origin and the destination of the flight, as well as the enroute component of the airspace for the trajectory between these two points.

A “time bar” comprises the middle pane of the EFB display, which supports the capability to view future operational, airspace, and weather conditions along the trajectory. The vertical view comprises the lower pane of the EFB display, wherein current altitude and terrain information within 200 feet above and below the current altitude are depicted. However, during departure and arrival operations, the vertical view includes depiction of the airspace 4000 feet above ownship when ownship altitude is below 2000 feet.

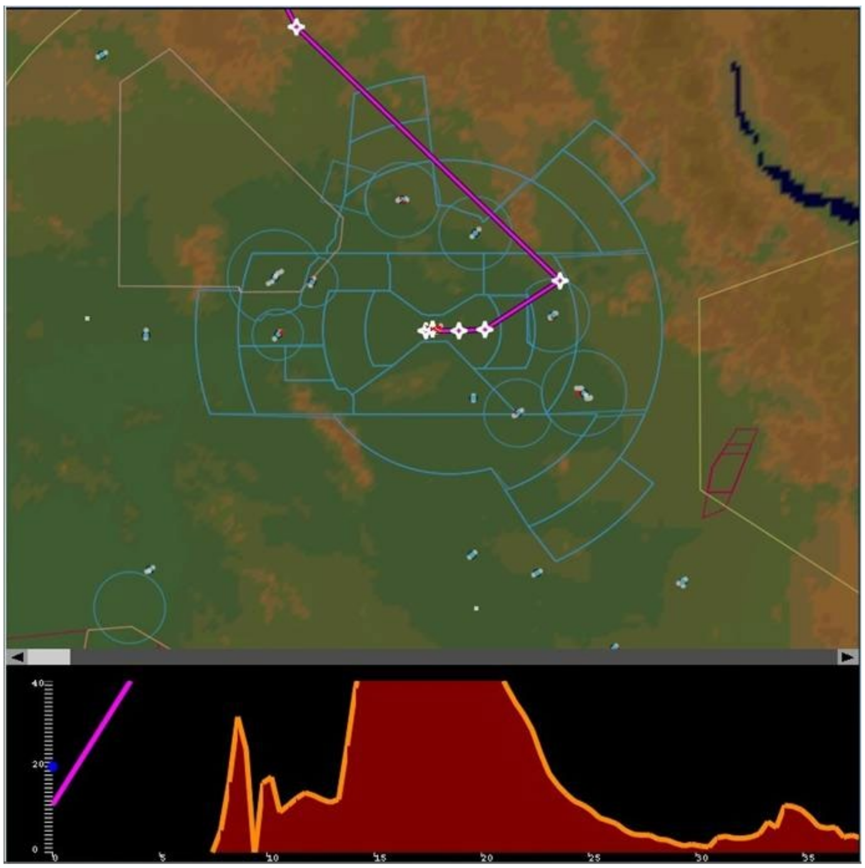

Figure 13. EFB first iteration of the lateral view (top), time slider (middle), and vertical view (bottom).

The first iteration of the EFB also included the design of an EFB display menu (see Figure 14). The elements of the display menu were as follows:

- **Top Pane**. The top pane includes the options of primary or alternate display:

    Primary: the main (default) display configuration, inclusive of current trajectory and its waypoints depicted on the main graphical display.

Alternate: the alternate route that is being negotiated (i.e., a proposed trajectory) and its waypoints depicted on the main graphical display.

– **Middle Pane**. Waypoint list with a scroll bar:

Waypoint list: lists the next 10 waypoints in the trajectory. The waypoints displayed in the list are tied to selection of the primary or alternate option for the top pane.

Scroll bar: allows the user to search up and down through the list of waypoints via a touch and drag gesture.

– **Lower Pane**. Provides the option to select among different layers of information to be displayed in the main graphical display:

L: Lateral display

V: Vertical display

Terrain: allows the user to select display of terrain information. By selecting the L or V options (or by selecting "both" options), the user will be able to display terrain in the lateral, vertical or both lateral and vertical views.

Weather: allows the user to select display of weather information (lateral view only).

Airspace: allows the user to select display of airspace information (lateral view only).

Traffic: allows the user to select display of traffic information (lateral view only).

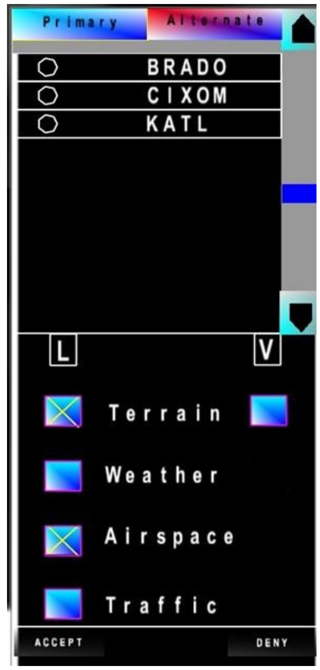

Figure 14. The first iteration of the EFB's Display Menu.

The second iteration of the EFB included a revised main graphical/trajectory display in both lateral and vertical formats (see Figure 15). In the lateral display, all information relevant to the lateral dimension of the current ownship trajectory and the alternate trajectory are depicted. This display can also provide supplementary waypoint information in parallel with the Information Pane (see below). The lateral display includes the following symbols:

– **Ownship.** The ownship symbol is white and is always located at the bottom center of the lateral display. The symbol provides a lateral depiction of ownship heading and its lateral/longitude position at a given moment in time.

– **Compass.** The compass is always positioned about the center of the lateral display, and parallel with the ownship symbol. The compass provides a secondary depiction of ownship's current heading.

– **Trajectory line.** The trajectory is depicted as a magenta line indicating the LAT/LONG path associated with the current trajectory.

Figure 15. EFB second iteration of the lateral and vertical display.

- **Waypoints.** A "star" symbol is used to identify waypoints. The star appears at the LAT/LONG position as identified on the current trajectory. Waypoint symbols are color coded as follows:

  Yellow Waypoint: The waypoint most recently visited. This is a waypoint that the aircraft is currently moving away from.

  Magenta Waypoint: The next waypoint in the trajectory along the route. This is a waypoint that the aircraft is heading toward.

  Green Waypoint: All the waypoints in the trajectory *after* the magenta waypoint that are included in the trajectory.

The lateral view supports gesture recognition. Pilots can <u>zoom</u> the display by placing two fingers on the screen and closing the distance between them (i.e., a "pinching" gesture); similarly, pilots can <u>magnify</u> the display by increasing the distance between the fingers (i.e., an "enlarging" gesture). It should be noted that zooming or magnifying the lateral display results in the same changes to the vertical display. Pilots can also select individual waypoints on the screen to display information about the waypoint, including ownship's ETA to the waypoint, ownship's RTA to the waypoint, the "delta" or difference between ETA and RTA, and "Early / Late" prediction.

Other touch functions include the time slider that is depicted between the lateral and vertical displays in Figure 15. The time slider is used to control the time value, which again allows the pilot to "take a look" into the future on both the lateral and vertical displays. When the slider is moved, current or future "represented time" appears in white centered above the scroll bar. Pilots can touch the scroll bar and slide it from the current time at the far left of the window to the end of the flight's trajectory at the far right. Alternatively, pilots can touch the arrows at the left and right of the slider to change the represented time value by +/- one minute.

In terms of the vertical display (bottom of Figure 15), the x-axis depicts the distance traveled (in nm) in the current trajectory at a given moment in time (recall that time is controlled via the time slider). The y-axis depicts ownship altitude in similar fashion. The ownship symbol remains centered at the left of the vertical display, the position of which represents ownship altitude. Similar to the lateral display, a trajectory line is depicted in magenta, and "star" symbols are depicted for waypoints along the route at the appropriate x- and y-coordinates. Terrain is depicted on the vertical display as an orange line when enabled via the display or layer control (see below).

The second iteration of the EFB display menu (also referred to as "layer control") is depicted in Figure 16. The changes from the first iteration included removal of color gradients and the use of green ovals to indicate selected layer elements for depiction on the EFB's main graphical/trajectory display. The various options control display of terrain (i.e., on the lateral display, vertical display, or both), weather, airspace, and traffic.

Two new display panes were created for the second iteration, including the "waypoint list" pane and the "information" pane. The waypoint list pane depicts a list of up to ten of the waypoints on the current trajectory (see Figure 17).

Figure 16. Second iteration of the EFB display menu.

Figure 17. EFB waypoint list.

– Waypoints associated with the current trajectory appear in chronological order on the waypoint list and are identified via their associated Waypoint Name. Waypoint Names are color coded in the same manner as described above for the lateral and vertical displays. The most recently selected waypoint is annotated with a white arrow, and the list includes a scroll bar that the pilot can touch and move in similar fashion to the time slider described above.

– The information pane provides textual information relating to the EFB's display attributes (see Figure 18). Pilots can select individual waypoints on the screen to display information about the waypoint, which appears in the information window. The information includes the selected waypoint, ownship's ETA to the waypoint, ownship's RTA to the waypoint, the "delta" or difference between the ETA and the RTA, and "Early / Late" prediction. At the bottom of the information pane are two additional lines, "Time" and "Elev". "Time" represents the current time value in the aircraft trajectory that is associated with the time slider function discussed above. Similarly, "Elev" represents the current ownship altitude associated with the time slider.

Figure 18. EFB information pane.

Multi-function Control Display Unit

The MCDU was revised to incorporate RTA functionality, based on Subject Matter Expert direction. There are four pages of information tied to the RTA function, including:

– FMS determination that ownship can meet the RTA;

– FMS determination that ownship cannot meet the RTA;

– When on the ground, FMS determination that ownship cannot meet the RTA, with an associated Required Time of Departure (RTD) of As Soon As Possible (ASAP); and

– When on the ground, FMS determination that ownship can meet the RTA, with an associated RTD specified (see Figure 19).

Figure 19. MCDU RTA pages – clockwise from top left: can make RTA, unable to make RTA, unable to make RTA – RTD ASAP, can make RTA with RTD.

Method

After initial requirements and iterative prototyping efforts, a pilot heuristic evaluation of the display and FMS enhanced prototype was executed. This incorporated a human-in-the-loop evaluation of selected NextGen TBO scenarios.

The three flight deck displays – MCDU, GFP, and EFB – designed to depict RTA performance were evaluated for human factors heuristics and subjective impressions from a sample of seven current pilots using a rapid prototyping fixed-base flight simulator. The displays were used to support pilots in the completion of a series of abbreviated cross-country flights that incorporated an RTA constraint. The evaluation included a host of subjective ratings and comments from the pilots.

Participants

Seven pilots were recruited to participate in the evaluation; most were current Airline Transport Pilot (ATP)-rated pilots, a subset of which were also commercial and instructor pilots. The pilots' current aircraft included the Embraer 145, Boeing 727/737/757/777, Airbus A320/330, Gulfstream 550, Citation 560XL/680/750, DC-3/9, and the Convair 580/640. Current crew positions included 5 Captains and 2 First Officers, with 3 Test Pilots, 1 Check Airman, and 1 Instructor. Pilot ages ranged from 30 to 63 (mean = 44 years, standard deviation [SD] = 13 years) (see Table 2). Pilot flight hours ranged from 2,500 to 21,000 (mean = 6,914 hours, SD = 6,373 hours).

Table 2. Participant data.

Age, Mean (Range)	Total Flight Hours, Mean (Range)	Current Aircraft Types (List)	Current Crew Position (List)	Current Ratings/Licenses (List)
44 (30-63)	6,914 (2500 – 21,000)	Embraer 145; B-727, B-37, B-757,B -77; Convair 580, 640 Citation 560XL, 680, 750; DC-3, DC-9; Gulfstream 550; A-320, A-330	5 Captains 2 First Officers 3 Test Pilots 1 Check Airman 1 Instructor	4 ATP 3 Commercial & ATP, 2 Commercial, ATP, & Instructor 2 Private Pilots

Apparatus

The Honeywell Aerospace Tool for Rapid Advanced Cockpit Simulation (TRACS) located in Deer Valley, AZ was used for the evaluation (see Figure 20). TRACS is a flight deck prototyping and evaluation system that was designed to increase the speed of and reduce the costs associated with flight deck development activities. TRACS allows for the integration of weather, traffic, and terrain, and can support real-world displays, controls, and aircraft modules within the system, such as Honeywell's DU1310 displays, Multifunction Keyboard, and Enhanced Ground Proximity Warning System (EGPWS).

Figure 20. Honeywell TRACS facility, Deer Valley, AZ.

The TRACS facility was configured for the evaluation as follows:

- Aircraft model and Electronic Flight Instrument System (EFIS) of a Dassault Falcon.
- EFIS Control Panel.
- Mode Control Panel (MCP).
- Flight Management System (FMS).
- Autopilot (AP) and Autothrottle (AT).
- Conventional control column, rudder pedals, trim control, gear, flap and spoiler selection controls.
- Panel-mounted Navigation Display (ND) displaying the graphical flight plan display. The MFD was positioned to the right of the Primary Flight Display (PFD).

- Panel-mounted touch screen display displaying the MCDU. The MCDU was positioned to the right of the pilot's seat within a center console.

- An articulating arm-mounted Dell Inspiron laptop computer displaying the EFB. The EFB was positioned to the left of the pilot's seat and the articulating arm supported presentation of the laptop's display at the discretion of the pilot. It should be noted that the planned pilot interaction method for the EFB is using a touch screen interface, but pilot's used the laptop controls (keyboard, mouse) for the evaluation due to a software limitation.

- The external (out-the-window) simulated view was projected onto a 12' X 12' screen via a Mitsubishi FL7000U 3-LCD 1080p projector. ATC radio communications associated with other traffic were not included in this study.

- Microsoft Flight Simulator 2010 software was used as the simulation environment to provide both the aircraft model along with out-the-window visuals. A projector provided a semi-realistic out-the-window representation of the external topography airspace and airports (i.e., KPHX, KBZN, KMIA, KIAD, KDTW; see below) selected for this evaluation. These capabilities provided the means for creating and presenting specific operational conditions for each evaluation scenario.

Evaluation Scenarios

Scenarios were designed with consideration of operating conditions that would help to assess the display concepts' capability to effectively convey the RTA operation. Three experimental scenarios were developed, which took place in the simulated airspace and airports of KBZN, KPHX, KMIA, KDTW, and KIAD (see Figure 21). Flight routes were selected based on the following criteria:

- Wind-optimized routes according to the Global Data Center.

- Recently cleared routes.

- Routes without radar vectors, i.e., supported most own-navigation RNAV.

- Q-Routes that fit naturally with the routing.

- Inclusion of a direct segment.

- Inclusion of a possibility for a route change.

In general, scenarios and routes were selected that were possible in the real world, today. That said, real TBO and RTA benefits would be associated with routes that might look very different. For instance, in the KBZN-KPHX scenario (discussed below), in the arrival from Drake VOR, the better route for the RNAV GPS Y RWY 7L KPHX should go south to some RNAV Initial Approach Fix (that does not currently exist) rather than requiring a route southeast to PXR, only to double back.

In terms of the RTA window, while a +/- 30-second time constraint was contemplated, the research team decided to use a 1 minute constraint based on current FMA prototype capabilities from a Honeywell FMS expert. The scenario descriptions are summarized as follows (see Appendix A: Briefing Guide and Scenarios for detailed scenario descriptions, inclusive of waypoints along the routes and pilot-ATC communications).

- **KPHX – KMIA:** During terminal area and enroute thunderstorms, departure and approach routes can change substantially to circumnavigate aircraft around dangerous phenomena such as turbulence, lightning, and wind shear. The plan can evolve quickly. The scenario for PHX-MIA began with a plan to the most direct airway and q-route, i.e., a south route around the White Sands special use airspace (SUA). Then storms developed around TUS and SSO, resulting in ATC issuing a new clearance on taxi for a more circuitous north route around the SUA. This routing included a new RTA at JCT, but the same takeoff time. This route was selected to create a thought experiment: what discussion between ATC and the crew would likely take place? In the execution of this scenario, during taxi (but while stopped) at KPHX, the pilot was asked to make an enroute RTA sooner than was originally planned. The pilot was unable to meet the RTA, resulting in a revised RTA, due to a convective cell moving toward the flight path and forcing a deviation that increased the route distance over the enroute portion of the flight to KMIA. This deviation resulted in a revised RTA that is based on the updated flight plan.

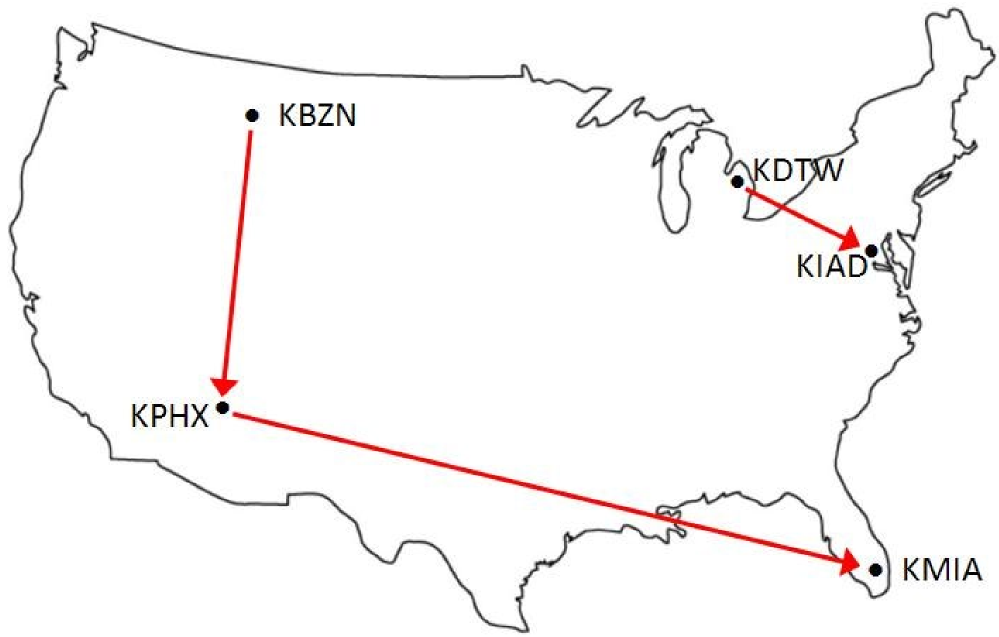

Figure 21. Scenario flight routes.

- **KBZN – KPHX.** After taking off from KBZN and while enroute to KPHX, headwinds are stronger than forecast, resulting in a steadily changing performance window. Without a correction, and despite the efforts of the FMS RTA system to adjust the speed target to respond to the winds, the flight is unable to meet the RTA. When the FMS makes the determination that the RTA cannot be met, the pilot reports "unable to comply" with the crossing time constraint.
- **KDTW- KIAD.** While enroute from KDTW, the pilot is informed that RWY 19C at KIAD is temporarily closed due to a disabled vehicle. The pilot is asked to meet the RTA one minute earlier than originally agreed due to increased flow to RWY 19L. The controller further states that if the pilot can meet the new RTA constraint, the aircraft would receive preferred routing to the feeder fix instead of flying a more lengthy arrival. The FMS determines that the revised RTA is too slow for the aircraft, resulting in the pilot rejecting the RTA. The thought experiment centered around pilot behavior if they were early, a condition that is typically considered "good" to pilots. If a crew cannot slow down enough, what would the procedure and conversation look like? If a few minutes early, would pilots really tell ATC or just show up?

Procedure

Pilots reported to the Honeywell TRACS facility in Deer Valley, Arizona. An average of 3 hours was required for each pilot to complete the evaluation. The evaluation comprised three sequential phases, each of which is discussed below:

- **Informed Consent, Evaluation briefing, and Familiarization (45 minutes):** an experimenter outlined the research goals and explained the nature of the evaluation. This included a description of TBO and RTA and demonstration of the display prototype conditions (i.e., MCDU, graphical flight plan, EFB) and an overview of the flight routes for each of the three flight scenarios outlined above.

- **Evaluation trials (1.5 hours):** the evaluation trials were presented in the order outlined in Appendix D: Counterbalance Order. Pilots were familiarized with the operational aspects of the scenario prior to the commencement of each scenario. The familiarization involved a general briefing of the procedure (e.g., "you are heading west on taxiway Echo at KPHX and will receive a request to meet a revised RTA soon after the trial begins"). The evaluation task began once pilots were sufficiently comfortable with the scenario details. Each pilot proceeded through the evaluation scenarios based on the aforementioned ordering. Pilots were requested to adopt their current standard operating procedures (SOPs) to the extent possible. During the scenario, the experimenter collected any real-time oral comments that the pilots made. Upon completion of each scenario with each display type, the pilot rated mental workload using the Modified Cooper-Harper scale. Pilots were instructed to provide their ratings in the context of the displays' utility in conveying RTA information during the scenario trial.

- **Post-Evaluation (45 minutes):** at the completion of all scenarios, each pilot completed an extensive post-experiment questionnaire soliciting feedback on all three display conditions, after which pilots and experimenters engaged in a debriefing during which the design of the displays and the TBO scenarios were discussed. Pilots were invited to provide unsolicited comments, criticisms, and recommendations for change.

Dependent metrics

Subjective impressions of the displays were collected via questionnaire (see Appendix B: Questionnaire), and subjective workload was collected via the Modified Cooper-Harper scale (see Appendix C: Modified Cooper-Harper Workload Rating Scale). Pilots were also asked a series of questions particular to the scenario conditions that were designed to elucidate their opinions on the use of the displays. Additionally, oral comments and feedback regarding the displays were captured by experimenters.

Results and Findings from the Heuristic Evaluation

Introduction & Summary of Relevant Results

The results of the evaluation are presented below, beginning with workload results, and then pilot comments collected from the evaluation scenarios about the displays, followed by pilot comments concerning other considerations for the RTA operation, and finally the questionnaire results.

Generally, pilots were supportive of the RTA procedures with respect to not only their perceived benefits from a "macro standpoint" or TBO overall, but also from a "micro standpoint" or their aircraft and its particular route. They wanted close coordination with ATC, especially in terms of rationale for RTA modifications, expectations, tolerances, and RTA negotiation possibilities. To this end, pilots want to have as much information available to them as possible to support assessment of a proposed RTA (e.g., forecast weather/winds aloft), as well as information to help them negotiate an RTA (e.g., cost index/fuel consumption). If there are problems with the procedures during conduct of RTA operations (e.g., unable to meet an RTA), then pilots want to be clearly notified about the problem as soon as possible (via visual, aural, or mixed-modal alerting) and they want clear procedures in place to aid in their resolution. In terms of pilot interfaces, pilots were supportive of entering RTA information in both the MCDU and the GFP, but were less supportive of performing the task via the particular EFB interface concept evaluated. Pilots were generally supportive of the GFP design of RTA information, and wanted quicker and clearer access to RTA functions on the MCDU. However, pilots thought that the EFB design, in particular, should be revisited.

Workload

Mean workload ratings for each display type for each evaluation scenario are depicted in Figure 22. Mean ratings for the PHX-MIA scenario ranged from 2 for the MCDU to 4.6 for the EFB. Mean ratings for the BZN-PHX scenario ranged from 1.9 for the MCDU to 5.1 for the EFB. Mean ratings for the DTW-IAD scenario ranged from 1.7 for the MCDU to 4.4 for the EFB. The workload ratings indicate that both the GFP and MCDU result in acceptable workload for pilots, whereas the EFB results in moderate workload for pilots. Thus, the EFB design should be revisited.

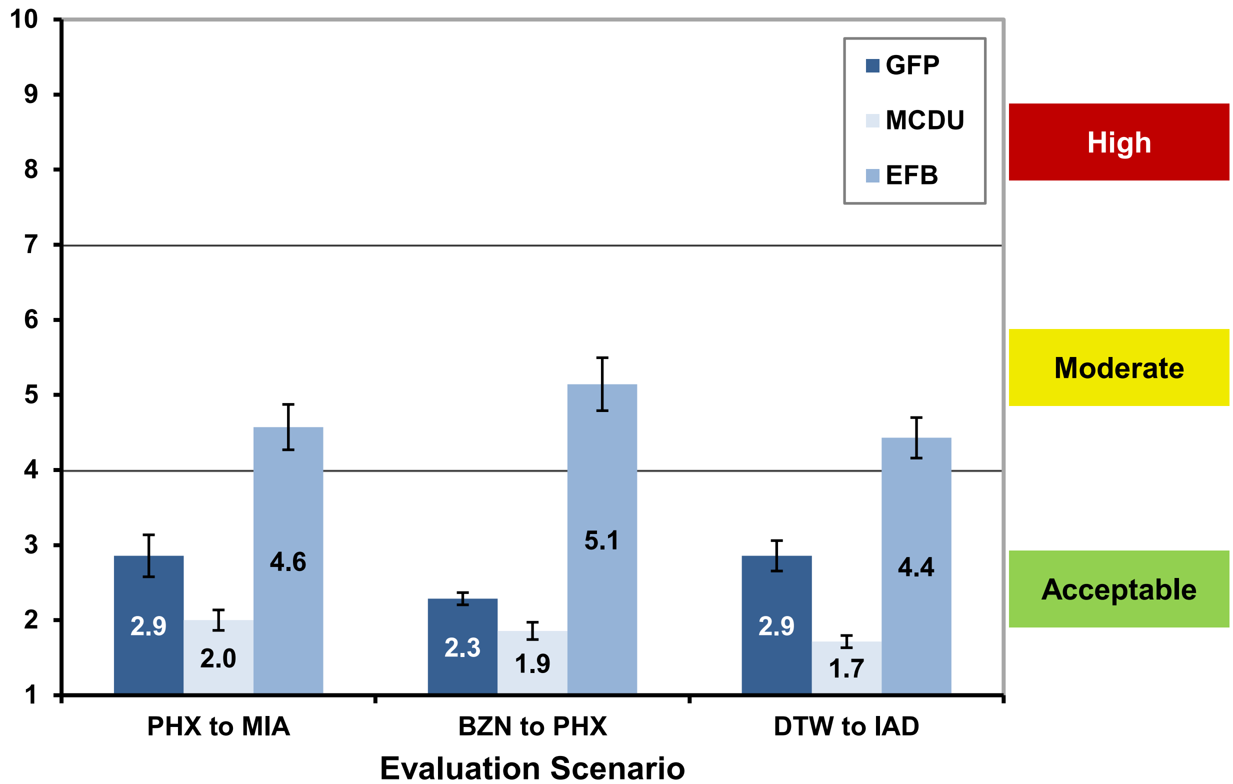

Figure 22. Mean workload ratings for each display type across evaluation scenarios, with 95% confidence intervals plotted.

Mean workload ratings for each display type collapsed across evaluation scenarios are depicted in Figure 23. Mean workload ratings were 2.7, 1.9, and 4.7 for the GFP, MCDU, and EFB, respectively. As noted previously, the GFP and MCDU resulted in acceptable workload for pilots, whereas the EFB resulted in moderate workload for pilots, suggesting that the EFB design should be revisited.

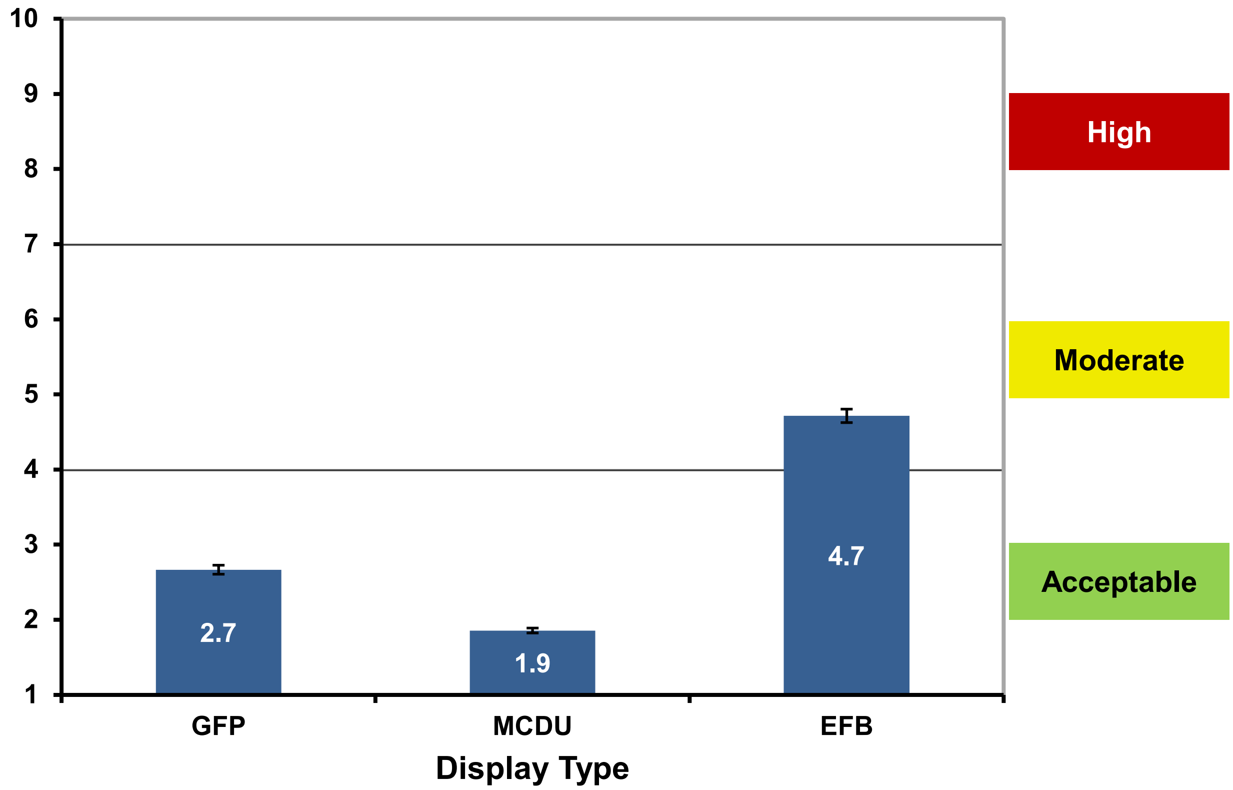

Figure 23. Mean workload ratings across display type, with 95% confidence intervals plotted.

Evaluation Scenarios

Pilots made several comments about the displays during the conduct of the evaluation scenarios. Outlined below are the comments and any other interesting or noteworthy occurrences that were captured, stratified by display type.

Graphical Flight Plan

- Most pilots wanted the current time displayed on the GFP.

- While one particular pilot "liked the display," that pilot also noted that the RTA information must still be entered via the MCDU. "If the information could be entered via the GFP, then that would be easier to view and can immediately be seen," suggested the pilot.

- Another pilot wondered how confident pilots would be with what the GFP was indicating in terms of an RTA unable message; e.g., "if the difference is only a minute or two, then pilots might try to make that up."

- A pilot thought that the RTA data characters were too small and thus too hard to see. The pilot commented, "The data tag should flash to draw attention, perhaps via an amber flash. As the unable RTA is amber in the FPLN list that would make sense – but if it is not visible (i.e., down in the waypoint list) it might be missed." The pilot was further unsure what "unable" is supposed to mean; i.e., whether it means that "We're giving all we can and we're unable, or is it because of some particular aircraft setting?" When asked what the ETA was, this pilot had to calculate it.

- Several pilots made the same general comment that the ETA should be depicted beneath the RTA waypoint row. "I expect this since all other values in the FPLN are ETA," said one pilot. Pilots were noted to have to perform "mental math" to determine what the ETA to the waypoint.

- A pilot asked, "Is there a way to make the FPLN in the GFP allow me to enter the same "what-if" type info for a particular waypoint that the MCDU/FMS does (i.e., select, enter, and see what the time would be))?"

- A pilot commented that the "picnic table" symbology seemed "very similar to the Station-Keeping Symbology that is used for C-130 and C-141 aircraft. In that display, there is a leader, and there is an associated ILS-type 'plus' symbol cue for up/down performance, and a little 'peanut gauge' with a slider that moves forward and backward for fast/slow performance." The pilot continued, "Pilots like to watch the window to catch trending information – this is where information about winds might come in handy." One pilot wanted to "build anticipation into the display. This could perhaps be a simple box, with early, late and an arrow to show trending information."

- One pilot wanted to see the same constraints that are on WPT LIST/FPLN to be indicated on the PFD. The pilot continued, "It's interesting that the system is showing a long way to the RTA waypoint, but it's showing me an RTA window of 1 minute. I can see the window as tight when you're 10 miles away from it, but when you're hundreds of miles away, the window should not be so tight as 1 minute—there's plenty of time/opportunity to tighten up that far out."

- One pilot stated that with the GFP's graphical view, pilots might be able to "at least understand what it's doing to you more quickly, which is a luxury pilots might not have with the MCDU/FMS. The ability of the GFP to magnify and maneuver and see what is going on takes less time than the other displays.

– One pilot had several suggestions for the RTA information. "Let's do away with the RTA tag entirely, and put it all in the FPLN. Change the color of the picnic table to amber anytime you're not in RTA tolerance. Show the ETA and show the RTA value. Also, could we have a speed restriction, similar to the ALT restriction, "at or above 5K" would be 5000, and where "at 5K" is line above and below 5000 in the FPLN list? Similarly, let's have an RTA with vertical lines before or after the time (i.e., vertical line before the time would be AFTER, vertical line after the time would be BEFORE, a line above and below the time would be AT; or can use less than/greater than symbols."

– One pilot suggested a feature for usability of the RTD information. "It'd be nice to click on the RTA waypoint (green box) and the FPLN autoscrolls to show the RTD."

Multifunction Control Display Unit

– One particular pilot thought that the MCDU was "the most useful display for RTA, largely because the display requires entry of all the relevant information which can then be seen and referenced."

– Another pilot commented, "Why not have the RTD on the same page as the RTA? (If it was there), then could immediately see what I can do instead of having to go to a different page to see it instead. There is space for it on the RTA page, so why not use it? What about an arrival time? Sometimes we go to an arrival time – like in the Air Force – we were scored by our capability to arrive at a certain place at a certain time (e.g., for a 'red carpet' for a General). This is a very similar concept to RTD. Another example of a window for arrival is when we have to meet a tanker en route on a long flight, such as IAD to Sydney." This pilot was noted to answer the new RTA request very quickly via reference to the early/late text on the MCDU.

– One pilot asked, "Can we have it like some radios today, where we just enter the last couple of digits and the system recognizes what the intent is and fills in the appropriate time? Pilots are all about fewer finger presses/data entry points."

– Several pilots did not like navigating the FMS pages. One pilot commented, "I can't assign an RTA to the waypoint using another page – such as the waypoint list – I have to go through the RTA page. Have it behave just like any other restriction – such as a crossing restriction. The page is divided in half, waypoints at left and constraints at right. Why can't I enter the RTA directly there in the constraint page for the RTA waypoint – be consistent with what pilots already expect of the MCDU."

- A pilot asked if the cyan RTA speed is the commanded speed, and whether the speeds represent speed limits. When the pilot was asked about when a decision would be made to call ATC, the pilot responded, "I'd watch to see when I would call them. I'd use the speed limits page to see if I was okay, trying to understand the performance that I have."

- One pilot commented, "Keep decimals out of the RTA page. If I weren't on the RTA data page on the FMS, I'd be looking for RTA information on the first page, such as a blinking message on the MCDU scratch pad. It's unrealistic to expect that crews will keep the RTA page up; they'll have the first page up almost all the time. So any RTA information needs to be on that first page, or the LEGS page.

- A pilot noted that the RTA speed conflicts with PERF climb page. The pilot commented, "So what should it be flying? VNAV is what is going to determine my RTA speed. What is the mode I'm in here? Crews have to be trained that when doing an RTA, the RTA speed limits override the FMS PERF speed values. We need to understand what mode the autopilot is trying to meet when in RTA mode. There's going to have to be something in the FMS bug – I'm trying to make it intuitive that I'm in an RTA speed mode, which is different from a VNAV speed mode – I'd like to see a different symbol on the PFD, you're going to have two modes, and that needs to be intuitive to pilots. Perhaps some kind of RTA code next to the speed tape would help, where the speed bug gets the tag when in RTA mode."

- One pilot suggested that the Mode Control Panel should have "something about the RTA procedure."

Electronic Flight Bag

- One pilot thought that the EFB was the least useful of the three displays, "largely because the information pilots need is ultimately still located on the MCDU."

- Another pilot looked at the ETA and the RTA, noting that they were both equal, which was the reason why the pilot knew that the RTA could be made. This pilot commented, "The only thing that's different is that I don't have the information available to me with the EFB, I don't know if I have a performance window I can play with."

- One pilot was not clear on the utility of the EFB. "Why are we having all of this information on an EFB when we have the MCDU for this information? To me, flying an EMB 145, this is neat to have, but the FMS is what I'm looking at for its textual descriptions. We depend on it. If we're unable to VNAV altitude, then we know by looking at it. I think the graphical depiction in the EFB is a good idea, but I'm looking in two different places. You may have FAA issues with that – unless you have an aircraft that has FMS that use purely steam gauges, 737s, Saabs, etc.; in that respect the graphical depiction is needed. But otherwise, not so much. I think you're better off having everything on the FMS: it has everything you're looking for."

- A pilot had to magnify the display so the RTA waypoint was "not occluded." The pilot was observed magnifying the display around the waypoint several times "because the compass/heading scale occluded the data block over and over again." At one point, the map was observed to move away from where the user set it. "The EFB is very cluttered and hard to see." "Why is there is no range scale on the map display? Colors and fonts are difficult to make sense of."

- A pilot thought that it was difficult to determine what the RTA window was with the EFB, while another pilot "would like to see a speed range associated with the RTA waypoint indicating whether the aircraft can make the RTA or not."

- Another pilot noted, "The ownship icon moves on the display as the time slider is moved, and I expected that the icon would instead stay positioned on the display where the aircraft is currently located and not move as well." This activity was particularly problematic because the pilot was "just looking ahead on the flight plan; this action makes me think I'm further along (the route) than I actually am." This pilot also wondered whether the time scale was "Based on plus-takeoff time or on Zulu time (it should be Zulu time because that is what the RTA is based on)?"

- A pilot who also used the time slider saw the ownship icon suddenly return to its original location on its own. This pilot also noted "If the y-axis on the VSD is really nautical miles (as the EFB Pilot Guide indicates), then there was a decimal missing ("It can't be that far!"); it was showing me 5000+ nm."

- One pilot saw the terrain "Suddenly appear and disappear on the VSD, which doesn't make sense."

- One pilot wanted to know about ETA performance at waypoints prior to the RTA waypoint, and was concerned about the EFB display size. "I want to know that I'm hitting the waypoints prior to the RTA waypoint at the right time as well – does this tell me that? I would almost like the RTA before the ETA on the RTA waypoint data tag – that way I can see what's important first. Also, I would think that since (the EFB screen is) so small it would be difficult to glean information from it in the turbulence."

- One pilot commented, "The EFB doesn't seem quite as intuitive as the GFP and MCDU – particularly with the RTA early late and range – I don't have anything to visually confirm the RTA unable. I'd like to see (in order, top to bottom) waypoint, RTA, ETA underneath that, and then the delta. I think that would be better as I'm not clear how that is displayed here. The EFB is hard to read; almost like it needs to be blown up more, there's very little detail that I can pull up; it needs to be formatted differently, larger font, and the error block below formatted differently."

- One pilot asked, "If the display is heading up, then why is the aircraft symbol not facing the way it's supposed to based on reality? Also, the course on the EFB is not in the same orientation as what I see on the panel. What's going to happen if there's a route discontinuity that hasn't been fixed, but then you're subsequently given an RTA? The system wouldn't be able to compute it I would think."

- One pilot had several comments about the EFB. "First, there needs to be consistency between the error terms and the RTA for the EFB. The RTD information is not easily accessible – I don't know if it can do that or how I can access it if so. I need to know what the weather is, and what ATC wants to get around it. I'd give an RTD based on what I think it would be, maybe with some small amount of time on either side of it. If on the ground, then I'd like to see a range for the RTD as well. I assume that ATC knows how long it takes to taxi out to the runway. But I just do not like the EFB at all in terms of the RTD."

Other Considerations for the RTA Operation

The following RTA considerations represent summaries of questions asked of pilots in between scenario trials (i.e., during the period between the conclusion of one trial and the start of the next trial). In some cases, direct quotes from individual pilots are reported.

Pilot Preferences for RTA Negotiations with ATC

Pilots generally indicated a preference for ATC to provide an RTA, and then pilots can respond with a WILCO/UNABLE. Pilots might also provide a "window" if that information was available to them, such as how early or how late they could make an RTA. Pilots generally want to work with ATC to make something work, and they believe that controllers are aware of their aircraft's performance capabilities so they generally are not asked to do something that their aircraft cannot do. One pilot suggested, "if there was a way to negotiate an RTA waypoint, then I could select it and it would give me a range, and then I can see whether I can make it and can immediately tell ATC." One pilot thought that a standard time frame would be useful. "I think there should be a standard error value; e.g., 21:30 with 5 minutes either side, and if I can make that then I'll respond yes or no. There may be confusion when ATC says, "This fix, this time" because I'm so used to hearing "this fix, this altitude."

Pilot Impressions about How Data Link may Affect RTA Negotiations

Pilots generally did not think data link would affect RTA negotiations, but there was some concern by at least one pilot that loss of the "party-line" communications might impact situation awareness in terms of weather in the vicinity. Another pilot thought that voice might be quicker in terms of providing explanations if ATC wanted to know the reason for a pilot's rejection of an RTA; this pilot also would want to know "why ATC is changing things." One pilot thought that data link would be "cleaner" because of its canned responses, perhaps with some free text capability, while another liked that data link will have a "hard copy of the message to look refer to at the pilot's leisure." One pilot expressed experience in developing NextGen data link, and commented, "The pilot will need decision-aiding for RTA options. The message set for negotiation is pretty much set. The pilot will need a quick response method for RTA options."

Pilot Impressions of the Timeliness of RTA Unable Alerting

Most pilots thought that it would be very advantageous to receive the RTA unable alert early, as "the further out you are the further out you can make an adjustment to make it." Generally, pilots thought that the earlier the alert was received, the better, as corrections cannot be made as easily as the "window shrinks closer to the RTA waypoint." In the case of a metering fix, one pilot stated that early alerting is advantageous because if all aircraft had the capability to perform RTAs, then operations would not be as random, and ATC would provide a speed. One pilot stated, "Everything about your flow is about going fast, and getting there quickly. But if we're going to get a penalty then we want to know about that ASAP." Another pilot outlined the timeliness this way: "My concern is – and this diminishes the further down the flight plan the RTA waypoint is – am I eating into my reserve fuel in the case of weather? What about landing weight? If the RTA is changing, then I feel like I'm losing a little control."

Pilot Thoughts on how they would like to be Alerted or Advised when an RTA is Becoming Undoable

Pilots generally liked the color change from green to amber for both the RTA data tag's text and for the "picnic table" symbology. Some pilots additionally wanted an "RTA unable" indication via text in the MCDU scratchpad area. One pilot suggested that the RTA data tag on the GFP and/or the EFB should flash as well, "perhaps accompanied by an aural alert since the EFB will not often be in the pilot's primary field of view." Another pilot thought that integrating RTA unable with a Crew Alerting System message might be useful as "your eye goes to those messages", along with some type of flag on the PFD. This is because pilots sometimes miss a scratchpad message. A pilot indicated a preference for an aural alert if there is a scratchpad message, but "the alert could be visual as long as it's more prominent." One pilot would prefer a visual message displayed in the middle of the PFD or Navigation screen with highlighted text. Another pilot suggested that the RTA alert/advisement be tied in with the Master Caution, "But I don't want nuisance flags. I consider an RTA an assignment so I need to know about it." In terms of situation awareness, one pilot asked, "Is it too much clutter to have the picnic table on the PFD – strung out on the 3D flight plan as well or even part of the primary display similar to the thrust director? Just as you have a vertical and lateral indication, you need an RTA indication for time – it may not need to appear until you're coming up on the RTA waypoint though." Another pilot suggested a new graphic. "How about a simple box or graphic, inside the early-late box, that tells you if you are trending outside of that?"

Pilot Impressions of Information about Why RTA Unable

Most pilots thought it would be useful to know why an RTA unable alert was received, such as winds different from forecast. One pilot stated, "We need to be accountable, and if we're unable to meet the RTA, then we need to be able to tell ATC why." A pilot stated that the delta shown in the RTA data tag, "Is good, but it does add complexity when we look at the FPLN to see if we understood why." Other pilots, however, were not so sure. "That kind of information means another place to have to look, and when a pilot is near or is on time there is a requirement to process that extra information." Thus, "Pilots might look at the tag first, and then at the FPLAN, which will make them have to think about it again and see if they matched up." Another pilot agreed, stating, "It would help to know why, because it could be a parameter that is controllable by the pilot." However, another pilot did not think there was a need to know the reason for an RTA unable message. "The crew should be able to determine why; usually, it would be their own fault for not updating the winds. There aren't that many variables that could affect this – mainly winds, route deviations, or weather deviations." One pilot wanted to know how the RTA unable is determined. "I'd like to know specifically what the system is looking at to calculate the RTA and early/late so I know what factors it's using, and if it's not using some factors, then I can factor those in."

Pilot Decisions Needed when Accepting or Rejecting an RTA

Generally, pilots would like to be able to assess the RTA by "plugging it in and seeing if I can make it" and incorporating information about "how close the time needs to be early/late." "The 'closeness' matters," said one pilot, because "if there is time on the front end of the ETA, then I might not make it," but if the time is "more center to the ETA, then I might make it." Essentially, the decision to accept or reject an RTA is based on pilot assessments of what the window is to make the RTA, versus the time that ATC wants them to be at the waypoint. A pilot commented, "If the difference is just a minute or so, then the decision would be to accept; but if it's 10 minutes, then maybe I do not accept." The pilot continued, "it would be nice to have two flight plans to assess – each with an RTA so that I can do trades between them." Another pilot indicated, "this decision is performance-related: if ATC is going to give an RTA to get to a waypoint quickly and the associated fuel burn, then a pilot may not want to or may not be able to do that." One pilot would like to know how much fuel would be remaining at the RTA waypoint given both options. "I'd rather have that than fuel left at landing," continued the pilot.

Wish List for Information & Comparisons Pilots Need to Make RTA Accept/Reject Decisions

Pilots want information such as forecast winds aloft, weather reports, accurate aircraft performance (e.g., prediction of fuel burn), and time over the fix. This information helps pilots to assess for trends which can impact decisions as to arrival times. Pilots would generally prefer to understand the aircraft's performance capabilities so that a yes/no response could be made quickly. Pilots would like the capability to display "what-if" conditions, such as flying a faster speed, or going DIRECT TO (to save time). Sometimes pilots may want to decline a faster route just because fuel or time is being saved. They recognize that this kind of analysis is largely up to the FMS in terms of determining how much fuel or time would be left. However, pilots want to be able to make modifications to see how they affect fuel burn and flight time. One pilot asked, "Is there a way this could be like the NextGen FMS – where it turns blue until I confirm it and then it turns magenta? I'm a fractional pilot – we don't really care about fuel costs, but I'd like to see a "what-if" type of comparison."

Pilot Decisions Regarding Fuel Consumption and Cost Index

A pilot commented, "If an RTA was given with an earlier time or a short cut when compared to the original flight plan, then that would be favorable in terms of fuel burn and cost index, but if it's a later time, then there might be a hold to meet the RTA, which would not be favorable in terms of fuel burn." Pilots also expressed the consideration that if a shortcut was accepted, then the aircraft might be too heavy for landing. Crews might be given a cost index that narrows the speed choices available to them, but they may nonetheless change the speed to make the aircraft go as fast as they want (e.g., FedEx, SWA). It also might be the case that pilots may want to decline the faster route just because fuel or time is being saved. Some pilots were interested in the amount of fuel at landing with the RTA: "If the weather is good, then I might give it some more gas to meet the RTA. If not good, then I'll cut myself more of a margin to see how much the RTA will cost me in pounds. I might negotiate it in good weather." Another pilot commented, "If the RTA is going to bite into your reserve fuel, then you may negotiate a different RTA. You can manage a changing speed or Cost Index, but those are just management tools – the decision is what it does to your fuel consumption. If you have plenty of reserve, then it becomes more of an arrival time issue. You might call dispatch to see if an early/late arrival impacts connecting gates." Pilots recognize that this kind of analysis is largely up to the FMS in terms of determining how much fuel or time would be left. However, pilots want to be able to make modifications to see how they affect fuel consumption and flight time.

Pilot Impressions of Entering RTA Data in the MCDU

Pilots generally wanted to access the RTA page quickly (e.g., "the fewer key presses, the better"). A pilot commented that RTA via MCDU could be made easier by having a "what-if?" page. Another pilot commented that it would be very useful to have the difference between early/late and by how much, as well as the RTD, on the same page.

Pilot Impressions of Using a Cross-dialog Box to Enter an RTA in the GFP

Pilots generally thought that using the GFP cross-dialog box would be as efficient and desirable as using the FMS/MCDU, and that the box seemed like a logical location to enter RTA information. One pilot thought that this was "a natural place to enter the RTA, as it would already be populated with information. I have it all I one place, and I like that." Another pilot commented, "It would be nice to have an RTA data entry field on the main display."

Pilot Impressions of Entering RTA Data in the EFB

Pilots generally were not amenable to entering data on the EFB. They thought it would be difficult to do so. One pilot commented, "It's nice for display purposes, but not necessarily for information input." Another pilot commented, "It doesn't really have any entry fields so it's kind of hard to imagine. But if I could select the waypoint, bring the RTA box up, and type it via touchscreen, then that'd be good. Then I can see what it does to me, but it needs an early/late window." One pilot commented, "If it was integrated with the FMS, then it would be appropriate. If it's not integrated or going directly to the FMS, then it's really not doing much good."

Questionnaire Results

Pilots were given a questionnaire to complete at the conclusion of all evaluation scenarios. The results are outlined below, including pilot comments.

Graphical Flight Planner

Graphical Flight Planner Symbology

Pilots were asked to rate various items on the GFP from 1 (worst) to 7 (best) in terms of their utility in conveying the item. Pilots were encouraged to provide comments regarding the items. Mean pilot ratings for the items were as follows: 5.7 for the *On-time RTA,* 5.6 for the *"Early RTA",* 5.6 for the *"Late RTA",* 5.6 for the *"RTA Data Tag",* 6.3 for the *"RTA Waypoint,* 6.4 for the *"Controllable Map Scale Range",* and 6.0 for the *"Controllable Map Scale Time"* (see Figure 24). The ratings suggest pilots thought that the GFP symbology was effective at conveying ownship's status during conduct of the RTA operation.

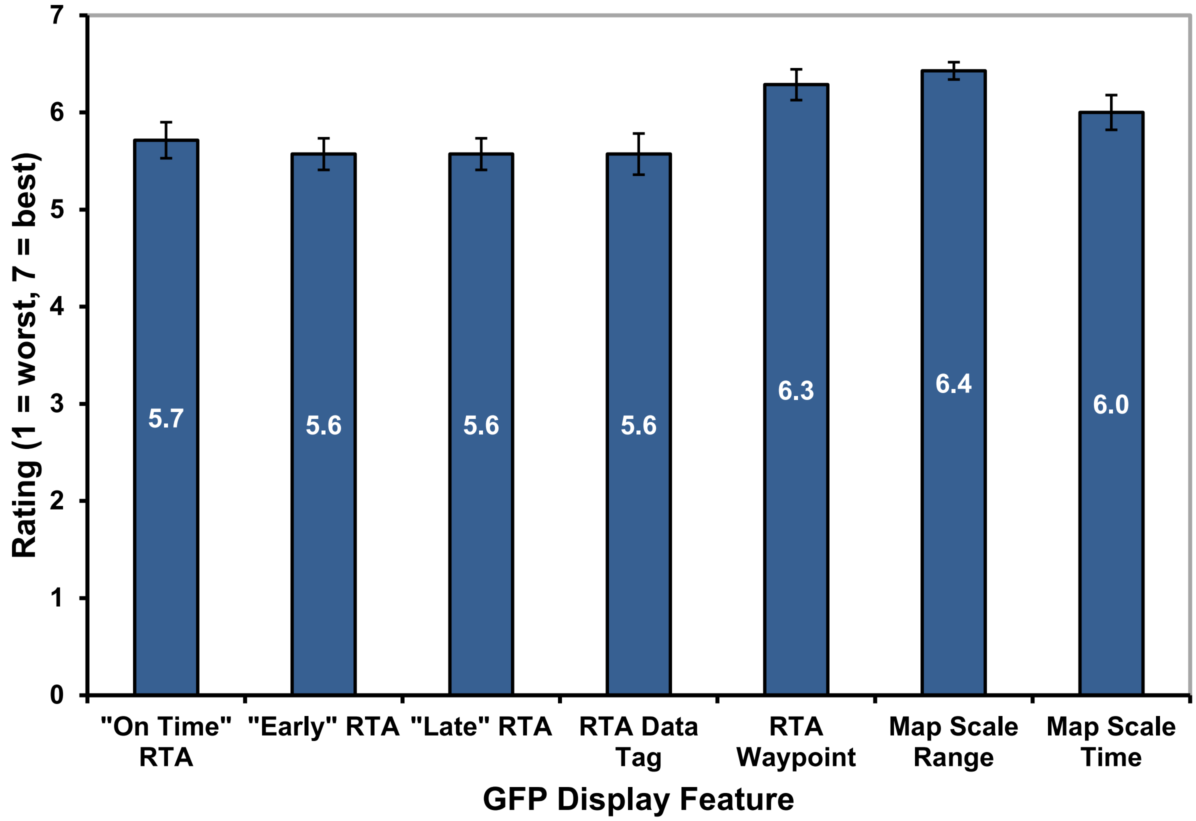

Figure 24. Mean pilot ratings for the various GFP display elements, where 1 = worst and 7 = best, with 95% confidence intervals plotted.

On-time RTA

A pilot who rated the symbol as "good" indicated that training might be required for pilots to recognize what the on-time RTA symbol signifies. Another pilot who rated the symbol as "good" commented, "I recommend changing the RTA symbol to amber when early or late parameter is exceeded, and to integrate a similar symbol on the primary flight display." A pilot who rated the symbol as "better" thought it was similar to the "Station-Keeping Equipment" display on C-130 and C-141 aircraft. A pilot who rated the symbol as "best" commented, "It could also be an "O" or doughnut which coincides with other 'ON' indications." A pilot who rated the symbol as "good" commented "I recommend changing the symbol to amber when an early or late parameter is exceeded." A pilot who was "neutral" about the symbol commented, "The color is okay, but the symbol needs to be larger/more prominent."

Early RTA

A pilot who rated the symbol as "good" indicated that training might be required for pilots to recognize what the early RTA symbol signifies. Another pilot noted that the symbol "jumped" from position to position, but assumed that it is supposed to be "smooth, and display relative error early or late". A pilot who rated the symbol as "good" commented "I recommend changing the symbol to amber when an early or late parameter is exceeded." A pilot who rated the symbol as "better" commented, "Maybe it should be amber." A pilot who was "neutral" about the symbol commented, "The color is okay, but the symbol needs to be larger/more prominent."

Late RTA

A pilot who rated the symbol as "good" indicated that training might be required for pilots to recognize what the late RTA symbol signifies. A pilot who rated the symbol as "good" commented "I recommend changing the symbol to amber when an early or late parameter is exceeded." A pilot who rated the symbol as "better" commented, "Maybe it should be amber." A pilot who was "neutral" about the symbol commented, "The color is okay, but the symbol needs to be larger/more prominent."

RTA Data Tag

One pilot who rated the symbol as "best" indicated that training might be required for pilots to recognize what the various elements of the RTA data tag symbol mean. Another pilot who rated the tag as "best" thought while that the tag conveyed concise information about the RTA, there was an instance when the tag read "unable" even when an RTA waypoint had not yet been entered in the flight plan. A pilot who was neutral about the tag commented "I like the tag but think it should be labeled more clearly", while another pilot who was neutral commented, "I suggest removing (the data tag) from the display and incorporating its information into the waypoint list."

RTA Waypoint

One pilot who rated the symbol as "best" indicated that training might be required for pilots to recognize what the RTA waypoint symbol signifies. Another pilot thought that the symbol correlates well with the "green box" RTA that exists in the FPLAN list. A pilot who rated the symbol as "good" commented, "Does this symbol change color? The green does not immediately make me think of RTA."

Controllable Map Scale Range

One pilot who rated the symbol as "best" indicated that training might be required for pilots to recognize what the map scale range symbol signifies. Similarly, a pilot who rated the controllable map scale range as "better" commented, "Familiarity lacks for this item due to lack of operational experience."

Controllable Map Scale Time

One pilot who rated the symbol as "best" indicated that training might be required for pilots to recognize what the controllable map scale time symbol signifies. Similarly, a pilot who rated the controllable map scale range as "better" commented, "Familiarity lacks for this item due to lack of operational experience."

Integrated Primary Flight Display

Pilots were asked to rate various items on the Integrated Primary Flight Display from 1 (worst) to 7 (best) in terms of their utility in conveying the item. Pilots were encouraged to provide comments regarding the items. Mean pilot ratings for the items were as follows: 6.0, 6.4, and 5.0 for the 3D Lines, Flight Path Marker, and Waypoint Symbols, respectively (see Figure 25). The results suggest pilots thought that the display elements effectively conveyed the location of waypoints and ownship's position relative to them and the flight path.

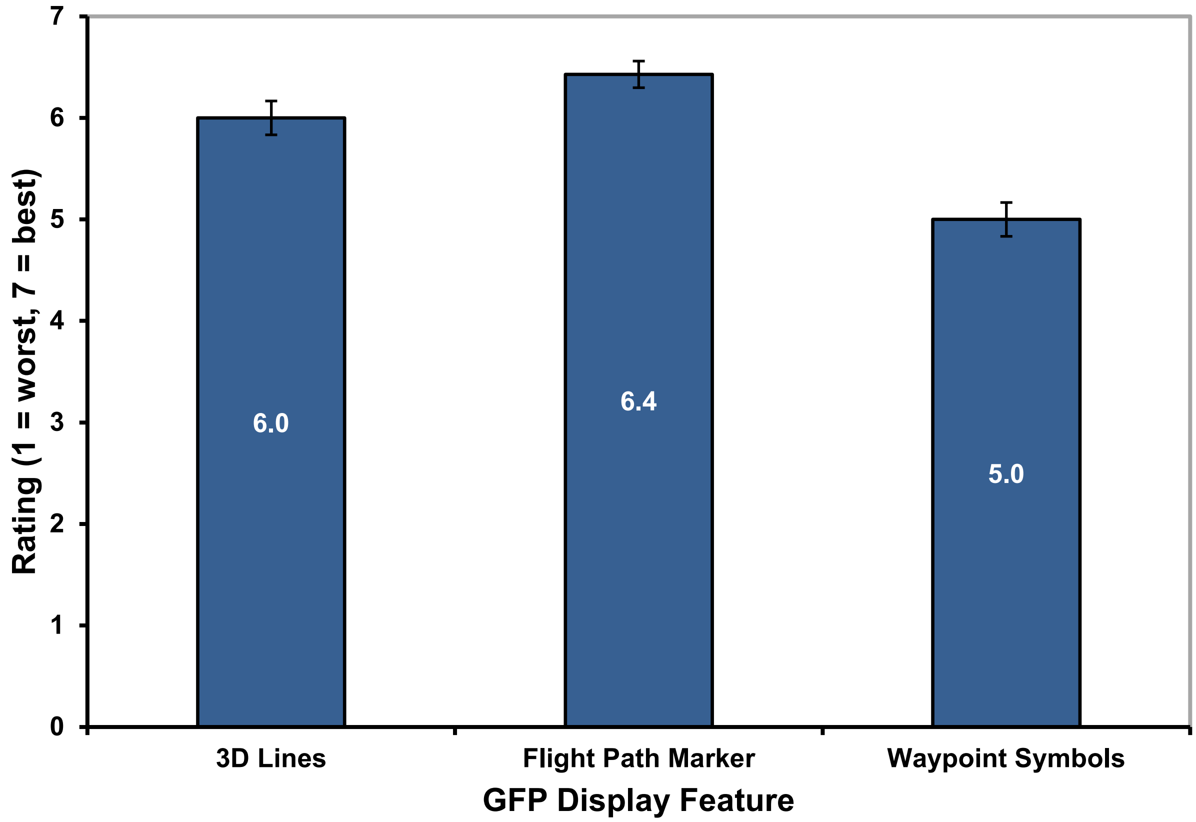

Figure 25. Mean ratings for various PFD items.

3D Lines

One pilot who rated the 3D Lines as "better" commented that the combination of symbols is very much like Highway-in-the-Sky symbology. A pilot who rated the lines as "good" commented, "I suggest adding lines for altitude constraints." A pilot who was neutral on the lines commented, "Slightly more saliency would help."

Flight Path Marker

One pilot who rated the marker as "best" thought that the "coloring is great."

Waypoint Symbols

One pilot who rated the waypoint symbols as "neutral" commented that they "seem like additional information which the pilot doesn't care about." Another pilot who rated the lines as "better" commented, "I'd like to see the waypoint labels next to the waypoint symbol with a line and a dot on the ground." A pilot who rated the lines as "good" commented, "I suggest adding lines for altitude constraints;" this pilot also repeated another's comment to "add the waypoint name next to its symbol." This pilot further commented, "You need to modify the airspeed bug to display VNAV speed mode vs. RTA speed mode."

Vertical Situation Display

Pilots were asked to rate various items on the Vertical Situation Display from 1 (worst) to 7 (best) in terms of their utility in conveying the item. Pilots were encouraged to provide comments regarding the items. The mean ratings were 6 and 5.2 for the VSD and the RTA in Waypoint List, respectively (see Figure 26). The ratings suggest pilots thought that the general design of the VSD and inclusion of the RTA in the Waypoint List were both effective at supporting the RTA operation.

RTA in Waypoint List

One pilot who rated the item as "best" commented that "the green box makes (the RTA in waypoint list) easily identifiable." A pilot who was neutral about the RTA in waypoint list commented "all of the waypoints show ETA except the RTA waypoint – I'd like it to show RTA, ETA, and the difference." A pilot who rated the item "good" commented, "add vertical bars to RTA – similar to ALT constraint bars; for example |7:15|."

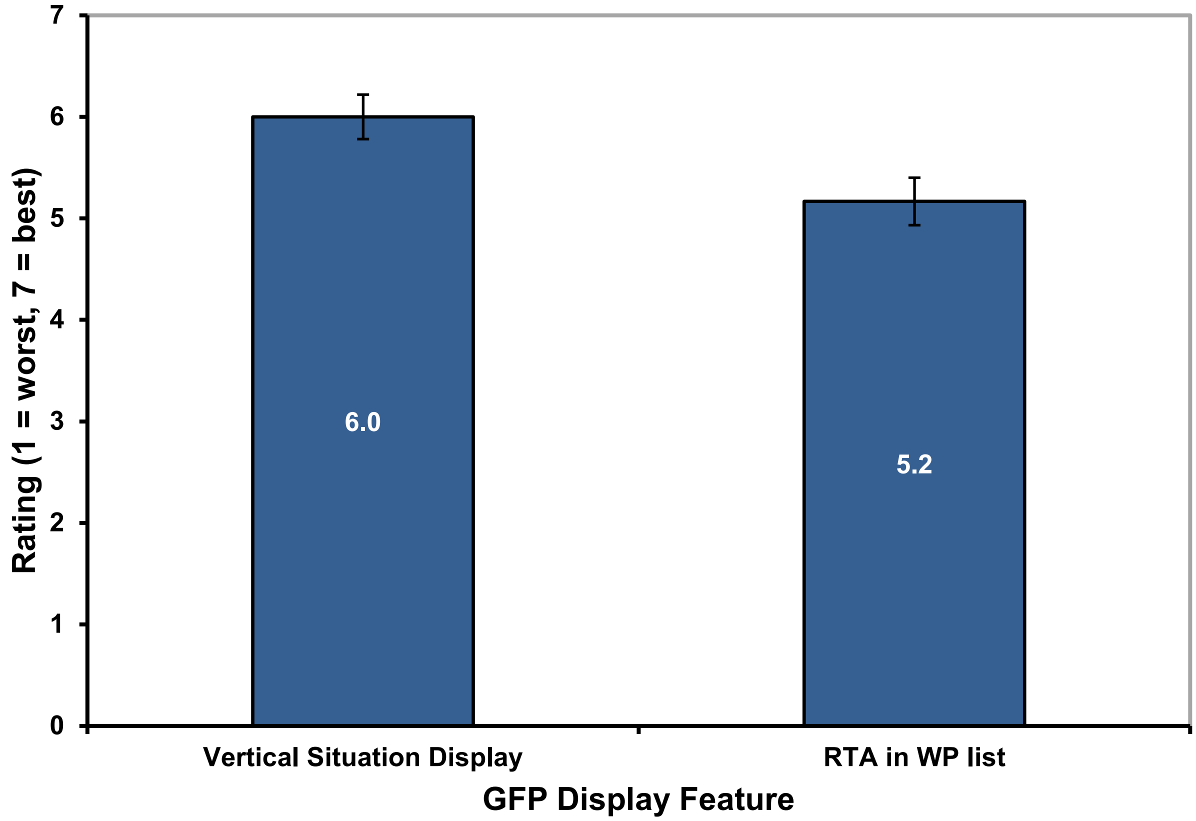

Figure 26. Mean ratings for the general design of the VSD and for Inclusion of the RTA in the Waypoint List as part of the GFP, where 1 = worst and 7 = best, with 95% confidence intervals plotted.

Display of "early" and "late" Next to RTA in FPLN Instead of "+/-"

Pilots were asked whether they would like to see the text "early" and "late" displayed next to the RTA numerals in the FPLN instead of "+/-". Five pilots chose "Yes", while 2 pilots chose "No" (see Figure 27). Pilot comments are stratified below between "Yes" and "No" responses:

Yes

- Using the text "early" and "late" would reduce pilot confusion; there may still be misinterpretation. In particular, there should probably be a "+" symbol to accompany the text "early" otherwise it might be misinterpreted. However, the term "late" seems easier to understand, especially with a "-" and amber text.

- Using the text would correspond to the language used to describe the earliest and latest times, but to avoid confusion the text must match the text used in the MCDU. The pilot also suggested that when describing “earliest”, the text should say “earliest” and not “early.”

- Pilots can think of early as a “+” or a positive, whereas engineers think of it as “late” – so I think “early/late” limits possible confusion.
- Most pilots have to stop and think about what +/- means (i.e., early or late). However, the “picnic table” symbol helps to alleviate the problem.

No

- “Pilots can understand this.”
- A “-” symbol makes me think “before” a given time and a “+” symbol makes me think “after”. I’d rather not have more text than needed.

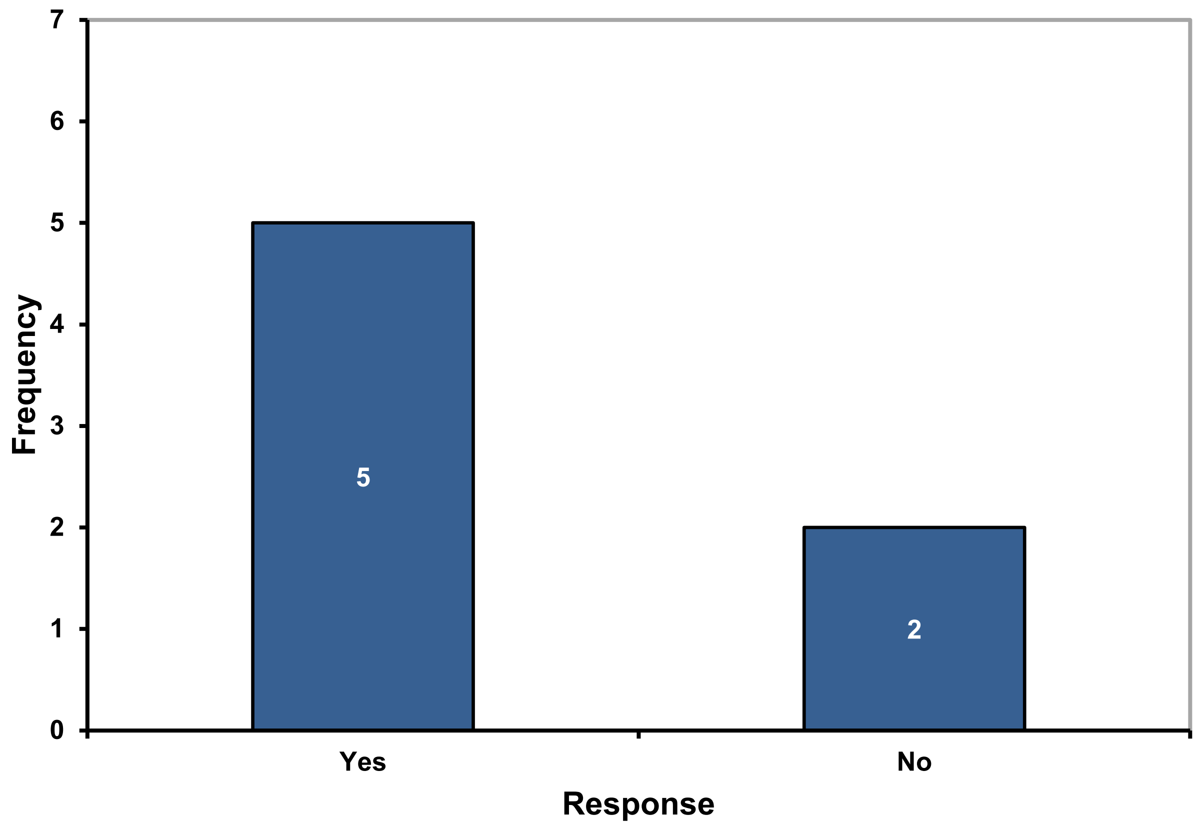

Figure 27. Pilot responses as to whether they would like to see "early" and "late" instead of "+/-".

Suggestions for Improving the Vertical Situation Display

Pilots were asked to provide their suggestions for improving the vertical situation display. One pilot commented, "(You) could add an RTA trend arrow paralleling the course."

Multifunction Control Display Unit

Pilots were asked to rate the MCDU RTA Pages from 1 (worst) to 7 (best). Pilots were encouraged to provide comments regarding the pages. Pilots were encouraged to provide comments regarding the items. Mean pilot ratings for the pages were as follows: 6.0 for the *Can Make the RTA* page, 6.0 for the *Unable to Make RTA* page, 5.6 for the *Can Make RTA RTD* page, and 4.4 for the *Unable to Make RTA RTD ASAP* page (see Figure 28). With the exception of the *Unable to Make RTA RTD ASAP* page, for which pilots were neutral, pilots thought that the MCDU RTA pages were effective in supporting the RTA operation; however concern about functionality being "buried" was noted.

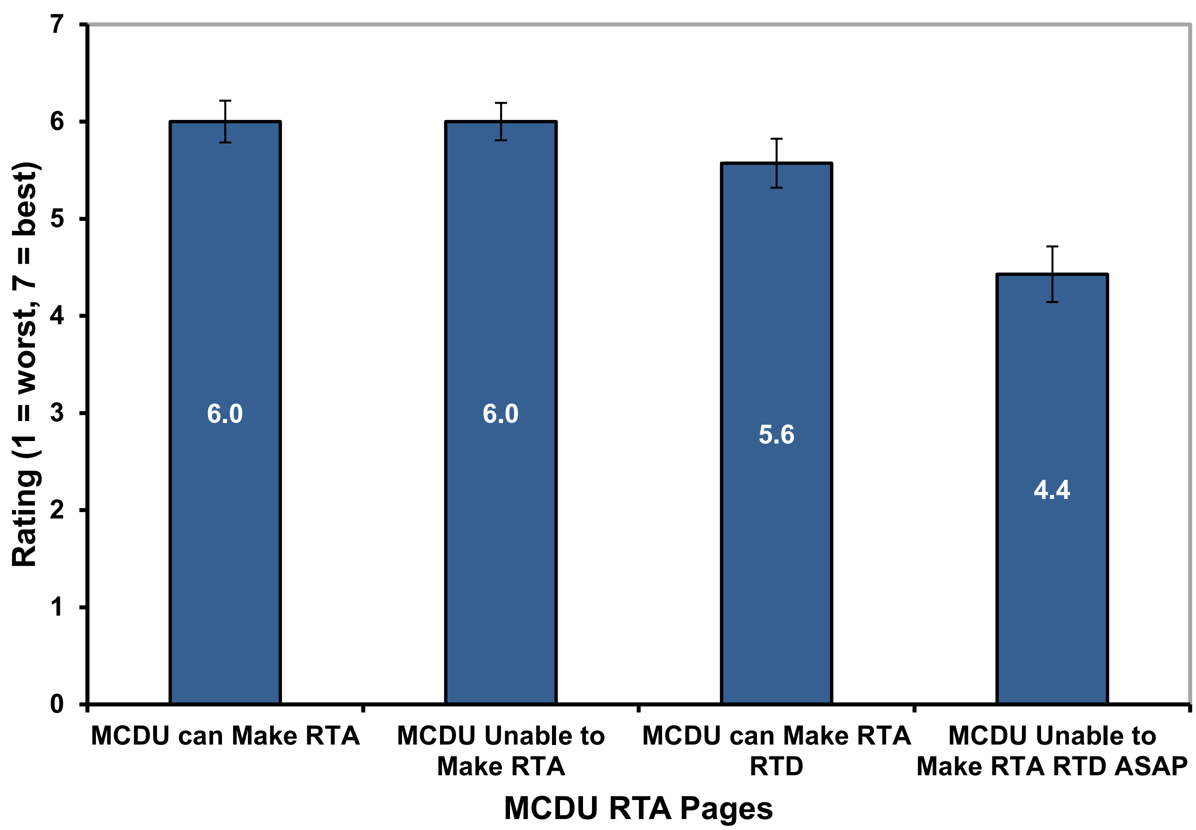

Figure 28. Mean pilot ratings for the MCDU pages, where 1 = worst, and 7 = best, with 95% confidence intervals plotted.

Can Make the RTA

A pilot who thought the page was "good" commented, "The RTD should be on this page. Early could be changed to "earliest" and "late" to "latest." The pilot continued, "Also, add a difference – ETA vs. RTA." Another pilot with a "good" rating commented, "I'd like more information; for example, fuel." A pilot who was neutral about the page commented, "This should be in the FPLN page data." A pilot who rated the page as "best" commented, "It's easy and simple to understand."

Unable to Make the RTA

A pilot who rated the page as "good" commented, "Tie it in with EICAS, chime, and master caution." A pilot who rated the page as "best" commented, "(It's) okay – the best place for (the unable RTA) is in (the) scratchpad." Similarly, a pilot who rated the page as "better" commented, "(The) scratchpad message is the key here, as pilots might not be on the (RTA) page when the message comes up." A pilot who rated the page as "neutral" commented, "I'd like more information about *why*."

Can Make the RTA RTD

A pilot who was "neutral" about the page commented that the RTD "should be moved to the main page," while another "neutral" pilot commented, "if you get rid of the first two pages (i.e., Can Make RTA, Unable to Make RTA), then you might need this page – otherwise, why isn't this on Page 1?" A third pilot who rated the page as "neutral" commented, "I'd like a range value." A pilot who rated the page as "better" asked, "Is this to make an early, late, or 'middle' RTA?"

Unable to Make the RTA RTD ASAP

One pilot who rated the page as "bad" commented, "I don't like ASAP being displayed", which "makes it seem like if I depart ASAP, there would (still) be a possibility of making the RTA." Another pilot who rated the page as "good" commented, "I'm not sure if this is the best labeling – it is unclear to me what ASAP means." A pilot who rated the page as "neutral" commented, "if you get rid of the first two pages (i.e., Can Make RTA, Unable to Make RTA), then you might need this page – otherwise, why isn't this on Page 1?" Another pilot with a "neutral" rating commented, "I would like to see a time value – it's too vague."

Suggestions for Improving the MCDU RTA Pages

Pilots were asked to provide their suggestions for improving the MCDU RTA pages. Suggestions included:

- Depict the RTA differently for instances when it was not possible to make the RTA (i.e., the term “ASAP” suggests that the RTA could still be made).
- Add RTA to a shortcut menu – need to reduce keystrokes, such as limit HH:MM to MM only in inputs, similar to radio frequencies.
- See if you can add RTA information directly via the FPLN pages.
- Add constraint bars for RTA times; e.g., |1750Z|.
- Less keystrokes to access the RTA page.
- More information on the RTA page.
- Reason *why* I am unable RTA.
- Provide “what-if” capability.

Electronic Flight Bag

EFB Symbology

Pilots were asked to rate various items on the EFB from 1 (worst) to 7 (best) in terms of their utility in conveying the item. Pilots were encouraged to provide comments regarding the items. Mean pilot ratings for the items were as follows: 4.3 for the *Aircraft Symbol – Lateral Display,* 4.9 for the *Aircraft Symbol – Vertical Display,* 4.6 for the *Compass,* 6.1 for the *Trajectory Line,* 6.0 for *Waypoint – Next,* and 5.8 for *Waypoint – Beyond Next* (see Figure 29). Pilot ratings were neutral regarding the Aircraft Symbol for the Lateral Display, suggesting that it could be improved, and the ratings for that symbol in the Vertical Display and for the Compass were “good”. There was more variability amongst the pilot ratings for these three items than for the other items. The Trajectory Line and Waypoint symbols were rated at “better” by the pilots, suggesting that those items were effective at conveying ownship status for the RTA operation.

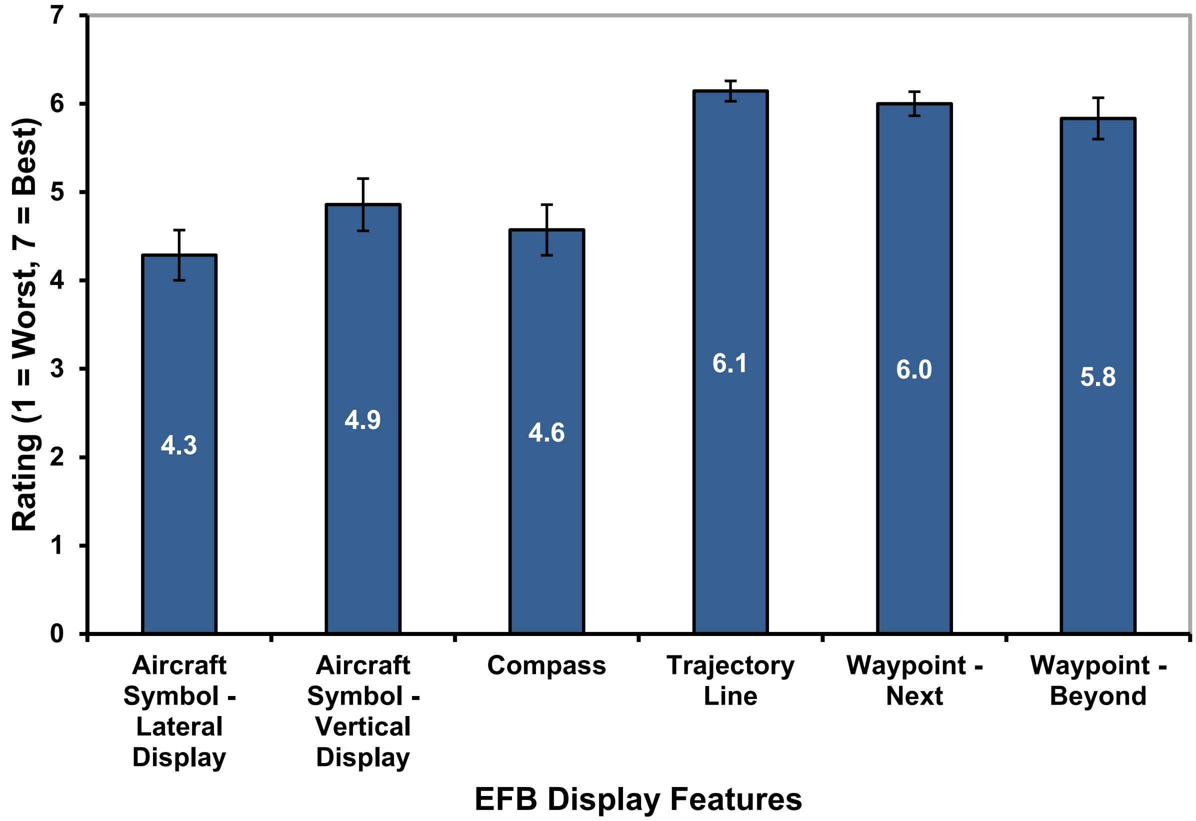

Figure 29. Mean pilot ratings for the various EFB display elements, where 1 = worst and 7 = best, with 95% confidence intervals plotted.

Aircraft Symbol – Lateral Display

A pilot who rated the Aircraft Symbol – Lateral Display as "bad" commented, "(The symbol) shouldn't move with time." Another pilot who rated the symbol as "bad" commented, "Can we set anything to a higher resolution?"

Aircraft Symbol – Vertical Display

A pilot who rated the Aircraft Symbol – Vertical Display as "bad" commented, "(Can we make it) configurable based on installation?" A pilot who rated the symbol as "better" commented, "A 172? Really?"

Compass

A pilot who rated the compass as "bad" commented that it was "limited." A pilot who rated the compass as "worse" commented, "I don't like the placement and the font size is too small."

Trajectory Line

No pilots commented on the Trajectory Line.

Waypoint - Next

No pilots commented on the Waypoint – Next.

Waypoint - Beyond Next

One pilot who was neutral on the Waypoint – Beyond Next symbol commented, "The green color seems to blend into the background." A pilot who did not provide a rating commented, "Unconventional color and poor contrast."

Acceptability of Various EFB Functions

Pilots were asked to rate the acceptability of various EFB functions from 1 (worst) to 7 (best). Pilots were encouraged to provide comments regarding the functions. Mean pilot ratings for the functions were as follows: 5.5 for the *Zoom Function,* 5.3 for *Selecting/Obtaining Information about a Waypoint,* 5.2 for the *Time Slider,* 5.3 for *Free Scroll*, and 4.5 for the *Scroll by Minute* function (see Figure 30). It should be noted that some pilots did not experience the function and thus did not provide ratings. This was largely due to software problems. For those pilots that did use them, the ratings suggest that the functions were "good" in terms of supporting what they were intended to; however it should be noted that in actual EFB map display, a range scale would be a required display element

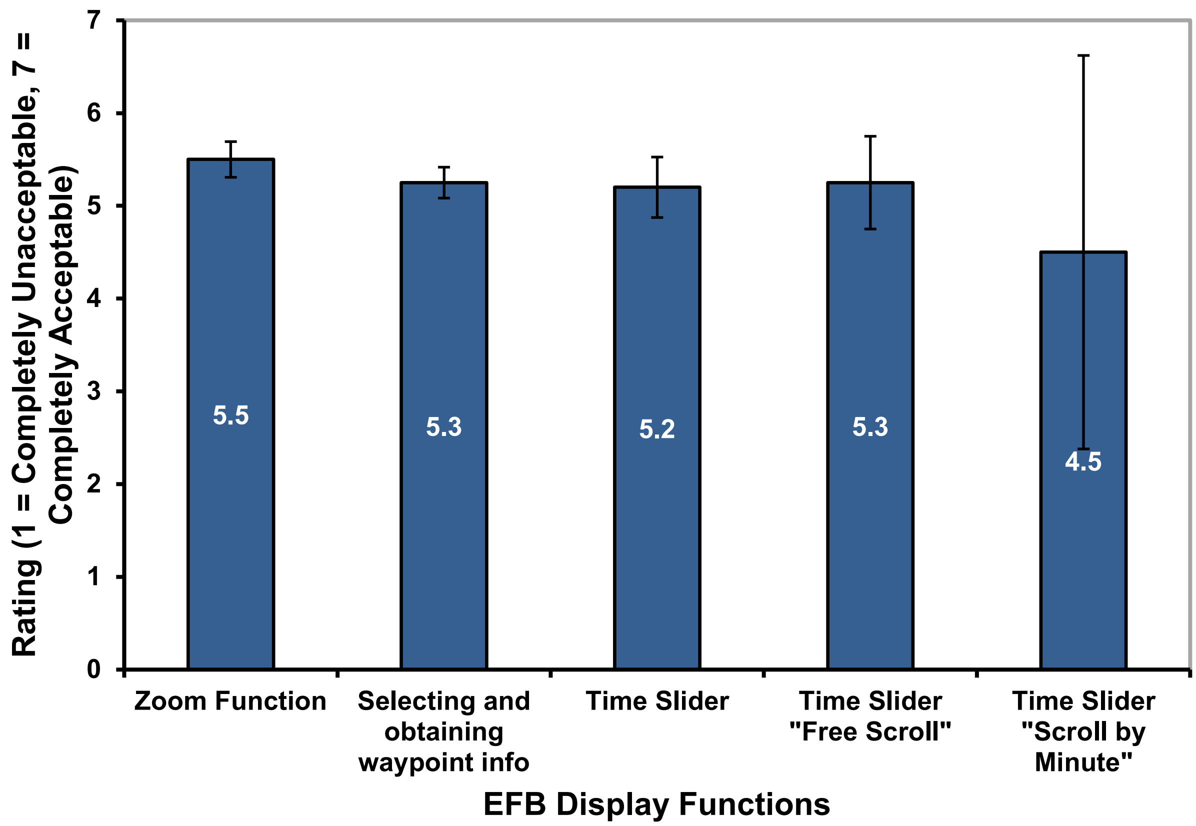

Figure 30. Mean ratings of acceptability of various EFB functions, where 1 = completely unacceptable and 7 = completely acceptable, with 95% confidence intervals plotted.

Zoom Function

A pilot who rated the zoom function as "acceptable" commented "it wasn't operative but sounds good in description."

Select and Obtain Information about the Waypoint

One pilot who thought the function was "somewhat acceptable" commented that the waypoints were small and "difficult to select." A pilot who rated the function as acceptable commented, "in congested areas, it may be difficult to hit the desired waypoint – may be easy to 'fat finger'."

Time Slider

A pilot who rated the function as “acceptable” commented, “The white airplane symbol moving with time should be changed. Normally, the white airplane symbol is the current position.” A pilot who rated the function as “somewhat unacceptable” commented, “I didn’t understand how this was beneficial.”

Free Scroll

A pilot who rated the function as “somewhat unacceptable” commented, “I didn’t understand how this was beneficial.”

Scroll by Minute

A pilot who rated the function as “somewhat unacceptable” commented, “I’m not sure how the time slider has value.”

Waypoint List: Text, Color, and Size

Pilots were asked to rate whether the Waypoint List’s text, color, and size were acceptable or unacceptable. Six pilots thought the text was acceptable, while one pilot thought the text was unacceptable. All pilots thought that the Waypoint List’s color and size were acceptable (see Figure 31). A pilot who rated the list’s text, color, and size as “acceptable” commented, “It seems like this could be laid out better, but I don’t have a great suggestion,” while another with the same ratings commented, “I suggest removing this part since the data is already on the MCDU.” A pilot who rated the text as “unacceptable” commented, “The active tab uses a yellow border, the font size is too small, and the font style is poor.”

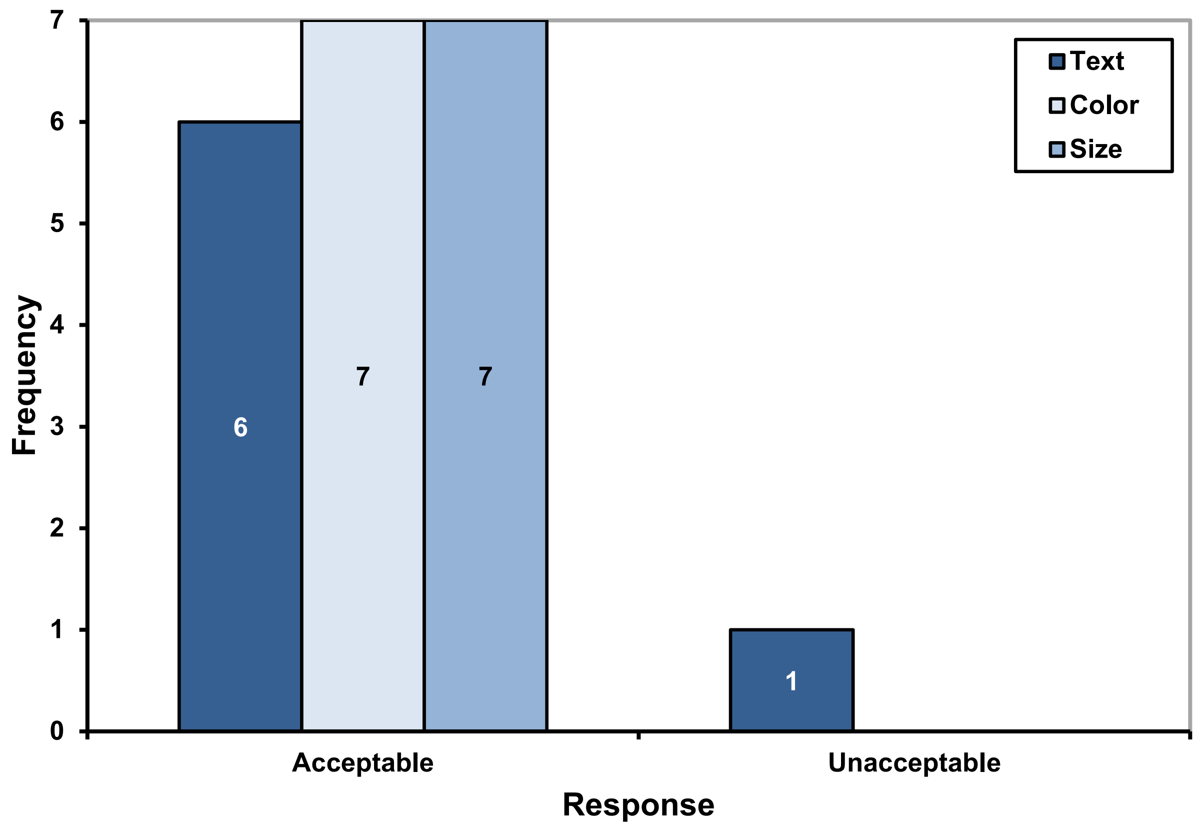

Figure 31. Ratings for the Waypoint List's text, color, and size.

Waypoint List: Significance of Various Elements

Pilots were asked to comment on what they thought the waypoint list's yellow text (i.e., most recently visited waypoint), magenta text (i.e., "TO" waypoint or waypoint "to be visited"), green text (i.e., future waypoints), and the white arrow next to the magenta text (i.e., most recently selected waypoint) signified. Two pilots were not sure what the white arrow signified, while another was not sure what the yellow text signified. One pilot thought that the white arrow signified waypoint information, while another though the arrow meant, "position." One pilot thought that the green text signified "next waypoint."

Information Window: Text, Color, and Size

Pilots were asked to rate whether the Information Window's text, color, and size were acceptable or unacceptable. Four pilots thought the text was acceptable, while three pilots thought the text was unacceptable. Five pilots thought the color was acceptable, while two pilots thought the color was unacceptable. Four pilots thought the size was acceptable, while three pilots thought the size was unacceptable (see Figure 32). A pilot who rated the color as “unacceptable” thought that the use of white text to convey “Late” seemed odd and should instead be more attention-grabbing. A pilot who rated the information windows text, color, and size as “unacceptable” commented, “I think RTA should be on top – this is not intuitive.” A pilot who rated all three items as “acceptable” commented, “There are no early or late parameters.” A pilot who rated the text as “unacceptable” commented, “The text is too small.” A pilot who rated the text and size as “unacceptable” commented, “The font size is too small, the window has poor separation of information, and should use ‘status’ colors to correspond with RTA early/late.”

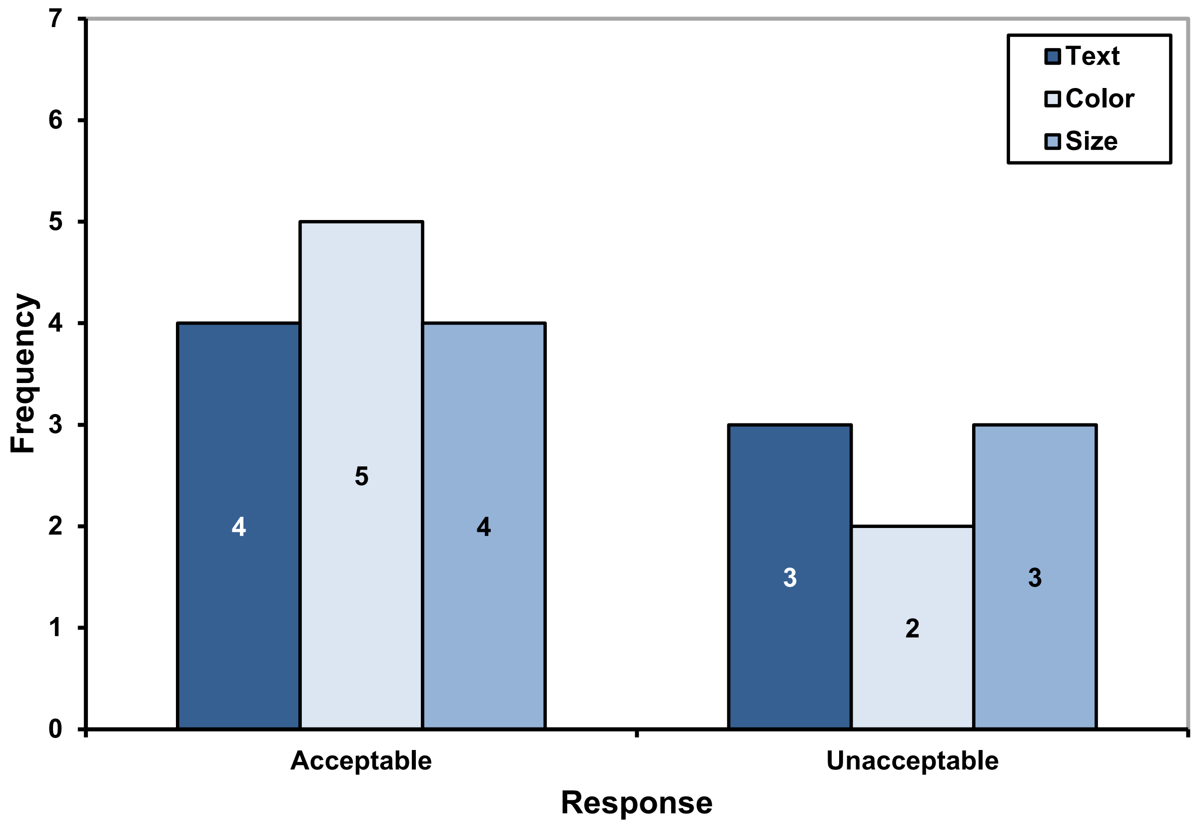

Figure 32. Ratings for the Information Window's text, color, and size.

Information Window: Relationship between the “ETA” Value and “Time” Value

Pilots were asked what they thought the relationship is between the value next to “ETA” (i.e., the estimated time of arrival for a selected waypoint) and the value next to “Time” (i.e., the current time value in the aircraft trajectory, or the time value when the time slider function is used). No pilots misunderstood the relationship between “ETA” Value and “Time” Value. Pilots were able to explain what each value meant, and there was no confusion between the two.

Layer Controller: Text, Color, and Size

Pilots were asked to rate whether the Layer Controller's text, color, and size were acceptable or unacceptable. Five pilots thought the text was acceptable, while two pilots thought the text was unacceptable. Six pilots thought the color and size was acceptable, while 1 pilot thought they were unacceptable (see Figure 33). A pilot who thought the layer controller's color was "acceptable", but who thought that the text and color were "unacceptable" commented, "I think it's difficult to read and not as intuitive as it could be." A pilot who rated the text and color as "unacceptable" commented, "(The information window) looks boring – all the same color; I'd prefer check boxes."

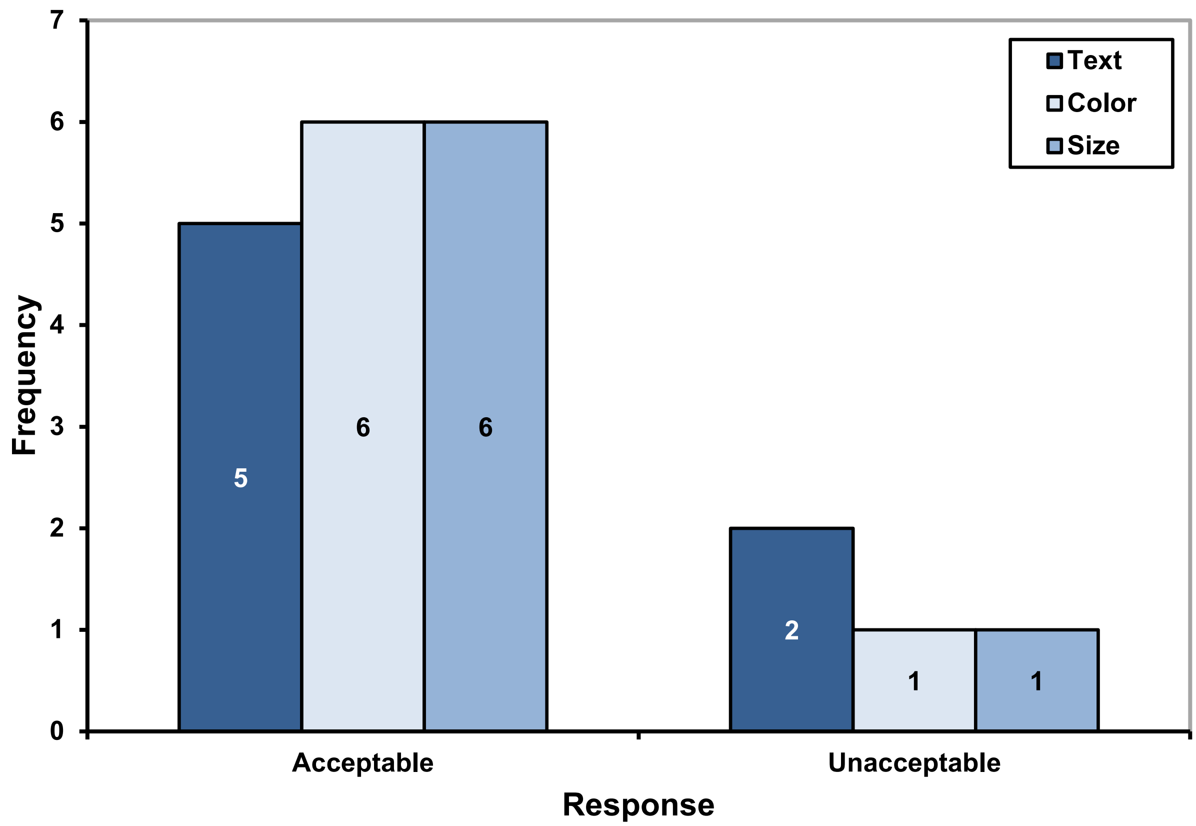

Figure 33. Ratings for the Layer Controller's text, color, and size.

Acceptability of Bottom Pane Functions

Pilots were asked to rate the acceptability of bottom pane functions, where 1 = strongly dislike, and 7 = strongly like. The mean rating for *"Using the arrow symbols on the Waypoint List scroll bar to view additional waypoints on the trajectory"* was 4.8, and the mean rating for *"Placing a Finger on the Labels of the Layer Controller to Toggle the Visibility of the Various Layers on the Display Ratings"* was 5.4 (see Figure 34). A pilot who "somewhat disliked" using the arrow function commented, “It seems like this would be difficult (to perform) in turbulence.” A pilot who “somewhat liked” the arrow function commented, “I need to be able to click on the waypoint list to select the waypoint.” A pilot who was “neutral” on the arrow function commented, “I would rather have bezel buttons.” This pilot was also “neutral” on the toggle visibility function, commenting, “There is no haptic feedback.”

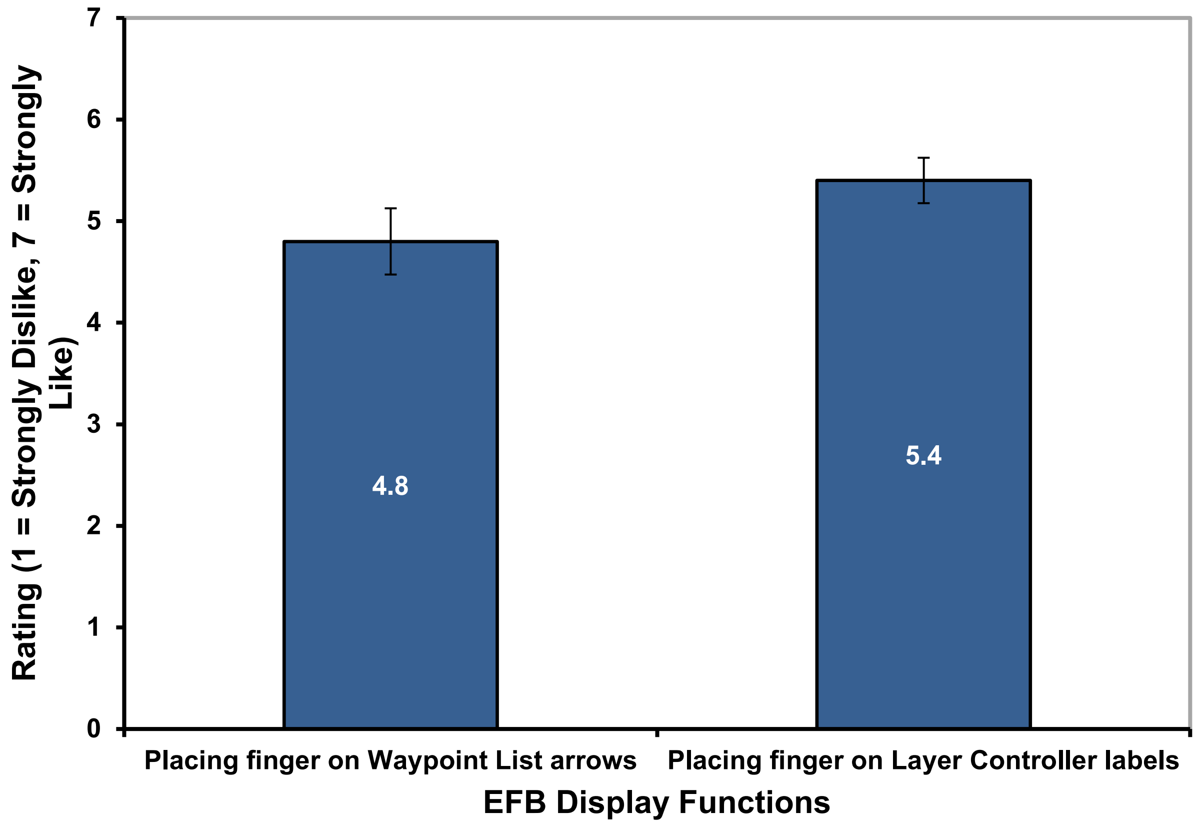

Figure 34. Ratings for acceptability of bottom pane functions, where 1 = strongly dislike and 7 = strongly like, with 95% confidence intervals plotted.

Improvements Pilots would make to the EFB

Pilots were asked to list any improvements that they would make to the EFB. Comments included:

- The EFB seems more like a place to view RTAs than a place to actually input RTA data.
- Add “earliest” and “latest.”
- I would like to see a higher resolution and a different layout. This was the least intuitive of everything I looked at.

- The closer to eye-level the better, and as far forward as possible—especially if they will present approach charts, performance data, or navigation data (as in the case of RTA information). The distance (of the EFB) from the pilot and the font size may make it difficult for some pilots to see.

- The text size is too small, and the format of the RTA display is unfamiliar. I would like the RTA value first, and then the ETA value.

- Start over.

Other Display Ratings

Pilots were asked to rate their level of agreement with various statements about the displays from 1 – 7, where 1 = strongly disagree and 7 = strongly agree (see Figure 35). Pilots were encouraged to provide comments about the statements. Mean ratings for the statement "*The display supports good decision making*" were 6.6, 6, and 4 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"The display is easy to learn"* were 6, 6.1, and 3.9 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"The display is uncluttered"* were 5.9, 6.4, and 4.1 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"The display kept me informed about what was happening"* were 5.9, 5.4, and 4.1 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"The display functional behavior was clear"* were 5.7, 5.3, and 4.4 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"The display has all of the functions and capabilities I expect it to have"* were 5.6, 5.4, and 3.6 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement "*The display will support me in meeting an RTA"* were 6, 5.6, and 3.6 for the GFP, MCDU, and EFB, respectively. Mean ratings for the statement *"I would enjoy having this display"* were 6.6, 5.9, and 3.9 for the GFP, MCDU, and EFB, respectively.

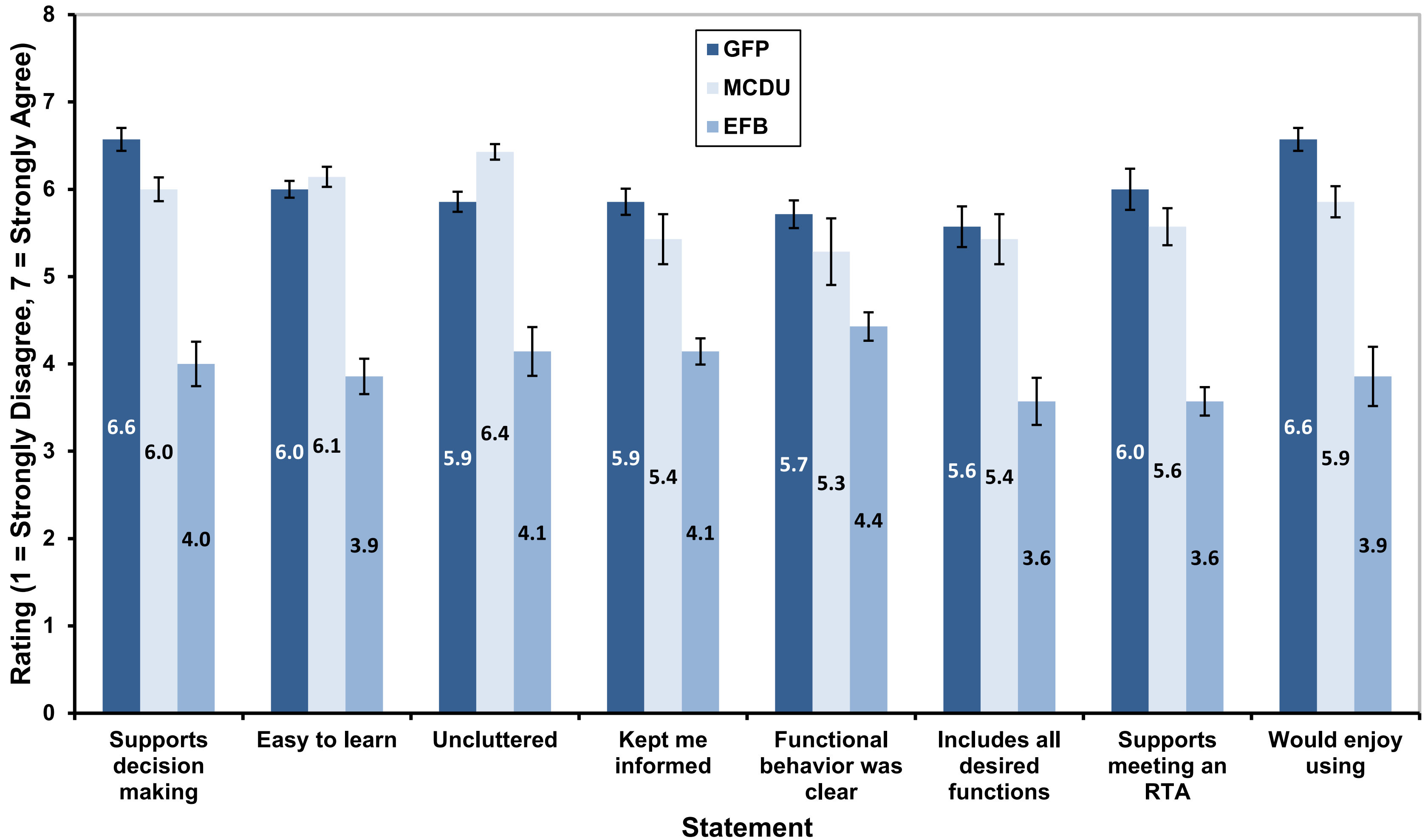

Figure 35. Mean ratings for levels of agreement with various statements about the displays, where 1 = strongly disagree and 7 = strongly agree

Generally, while pilots largely agreed that the GFP and MCDU designs met several qualities that support display design goals, the EFB resulted in more neutral ratings for those qualities. Pilot ratings suggest that the EFB design could be improved in several areas to support the desired qualities.

Good Pilot Decision Making

A pilot who “somewhat agreed” that the MCDU supports good pilot decision making commented, “I would like more information about the RTA.” No pilots made comments about the statement for the GFP or the EFB.

Easy to Learn

A pilot who “somewhat agreed” that the function was easy to learn commented, “It’s hard to navigate, but that has always been the case for MCDUs.” No pilots made comments about the statement for the GFP or the EFB.

Display is Uncluttered

A pilot who “somewhat agreed” that the GFP was uncluttered commented, “I don’t mind it being cluttered as long as I have control of display contents.” No pilots made comments about the statement for the MCDU or the EFB.

Kept Me Informed about what was Happening

A pilot who “agreed” that the GFP kept him informed added “(It) should be tied in with EICAS/master caution.” Another pilot who “agreed” for the GFP display commented, “add an INAV pop-up message when unable RTA.” A pilot who was “neutral” for the GFP display commented, “(There is) no way to easily explore “what-if” RTA options.”

One pilot who “agreed” that the MCDU kept him informed commented, “It seemed difficult to notice if you weren’t going to make the RTA after accepting the RTA, such as when conditions changed during the flight.” A pilot who “somewhat disagreed” commented, “There is no anticipation or trending information.”

One pilot who was “neutral” that the EFB kept him informed commented, “I would not be looking at it in normal cruise conditions.”

Functional Behavior was Clear

A pilot who "somewhat agreed" that the GFP functional behavior was clear commented, "Except for the confusion between Estimated Time Enroute and Estimated Time of Arrival, its functional behavior was clear. Maybe have better labels describing the various time values (would help)."

A pilot who "disagreed" that the MCDU RTA functional behavior was clear commented, "I had to figure out how RTA speeds override FMS speeds – training is suggested." Another pilot who "disagreed" commented, "I don't know why/how it was coming up with the time values."

No pilots made comments about the statement for the EFB.

Has all the Functions and Capabilities Expected

A pilot who "somewhat agreed" that the GFP has all the functions and capabilities expected commented, "It may have more display capabilities than I realized." A pilot who "somewhat disagreed" commented, "I need trend and anticipation symbology."

A pilot who "somewhat agreed" that the MCDU RTA function has all of the functions and capabilities expected commented "Add RTA and difference RTA vs. ETA."

A pilot who was "neutral" that the EFB has all of the functions and capabilities expected commented, "I did not use it enough."

Will Support Meeting an RTA

A pilot who "agreed" that the GFP will support meeting an RTA commented, "add an INAV pop-up message when unable RTA." A pilot who "somewhat disagreed" commented, "I need a way to evaluate time and fuel when I'm given a new RTA/new route."

One pilot who was "neutral" for the MCDU reiterated that it was sometimes difficult to notice (RTA unable) messages. A pilot who "somewhat agreed" that the MCDU would support pilots in meeting an RTA commented, "It tells me what I need to do, but not how or why."

A pilot who "disagreed" that the EFB would support meeting an RTA experienced difficulty "Seeing warnings". A pilot who "somewhat disagreed" for the EFB commented, "No more than the MCDU; add a pop-up to EFB when unable RTA." A pilot who was "neutral" on the statement commented, "There is not enough functionality available to really know how well (the EFB) supports (RTA operations)."

Would Enjoy Having

A pilot who "agreed" having the GFP would be enjoyable commented "can you put it in a B-757?"

A pilot who was "neutral" about enjoying having the MCDU commented, "It seems like I would have this information already (i.e., Estimated Time Enroute and ETA times on the FPLN page)."

A pilot who "somewhat agreed" that having the EFB would be enjoyable indicated that "I would like it if I didn't have to rely on it for making RTAs".

Three Favorite Features

Pilots were asked to list their three favorite features of each display. Comments for each display are discussed in turn.

GFP

GFP comments included:

- It's nice to have the RTA displayed, and it is also nice to have the "early" and "late" RTA times displayed in the RTA data tag, which helps to convey the range of possible crossing times.
- The GFP provided concise RTA information that did not add to clutter, provided on-time coordinated information via the aircraft symbol, green overlay, and the difference associated with the waypoint, and that the green RTA waypoint was "obvious."
- Early/late symbology.
- I liked the green waypoint identifiers.
- I like the idea of putting the RTA in the drop-down list.
- I like the VSD and terrain-mapping feature.
- The RTA block is clear and (makes it) easy to interpret data; it also keeps pilots "head-up" with data in their line of sight.
- The ease of identifying the RTA, ETA, RTD, and Estimated Time Enroute.
- The ability to alert the pilot by changing the color of the values.

- The immediate access to the error delta. For example, "I'm not going to make the time by 12 minutes."

- The early/late computations.

MCDU

MCDU comments included:

- Listing of the time range, RTD, and the "scratchpad" message if RTA unable.

- Easy to compare RTA capability.

- Ease of use.

- Easy to understand.

- Works as advertised.

- There's no clutter, it's all that is on the particular FMS page. Also, the MCDU is what I am most familiar with operationally.

- RTD time and the range of RTA.

EFB

EFB comments included:

- I want to be able to see an airspace overlay on the flight plan.

- Graphical depiction.

- I like the touchscreen even though it was not available for this exercise.

- The touchscreen features would be nice in smooth air.

- The additional information is always nice.

- It provides more control for scrolling.

– There were none.

Three Least Favorite Features

Pilots were asked to list their three least favorite features of each display. Comments for each display are discussed in turn.

GFP

GFP comments included:

– Some difficulty being notified that an RTA might be missed in some instances.

– It took a little extra time to compare the earliest and latest time vs. the RTA with the difference in minutes located above the ETA in the waypoint block; I was trying to correlate them I think.

– Lack of current time.

– RTA at RTA waypoint instead of ETA labels.

– Need a pop-up when unable to meet an RTA.

– Need to remove the textual RTA information from INAV.

– Need to add a "what-if?" function to compare RTAs/routes.

– For the purpose of this exercise, (having to use the) mouse instead of the cursor control device.

– The lack of information as to *why* we're not meeting the RTA. It would be nice to have immediate access to what the values being displayed are. For example, if we moused over a value and a descriptive text box (appears).

MCDU

MCDU comments included:

– The "RTD ASAP" message suggests that the RTA can still be made.

- Too many keystrokes to get there.
- It’s hard to find the page.
- I don’t like having separate page to enter waypoint and RTA.
- Having to be head-down. There’s no way to monitor the MCDU unless the page view is maintained; otherwise, the scratchpad message is the only way to know that there might be a problem.
- The lack of fuel information.
- The lack of reasons for why I’m not meeting the RTA.

EFB

EFB comments included:

- It was difficult to see “late” and “early” RTA warnings,
- The EFB was “really small.”
- I did not like that the EFB “would revert back to the TO/FROM waypoints when I was zoomed in on the RTA waypoint.”
- Display resolution and symbology.
- Format layout.
- Clutter.
- Text list at bottom.
- Unable to click on text to select a waypoint.
- I’ve got to be head-down to use it.
- It’s location – even though the location is not fully established.
- Readability in low-light conditions.
- The text is too small.

– It is out of my (forward) view.

– The controls are unfamiliar.

– Just about everything.

Discussion

The nature of this evaluation allowed for a constructive, open dialogue with pilots to gain insights about the specific prototypes and RTA operations as a whole. While this proved extremely valuable, there are also some associated issues brought about by this style of evaluation. Some of these issues and their implications are discussed here. In addition, some pain points associated with TBO implementation in general that were not addressed by this evaluation are described here, along with suggestions for future research to address these concerns.

Equipment

Generally, pilots were supportive of entering RTA information via both the MCDU and the GFP, but were less supportive of performing the task via EFB. In terms of monitoring RTA performance, pilots were generally supportive of the GFP design of RTA information, with some indicating that its graphical format supports quicker acquisition of the information needed to support situation awareness than did the other displays. Pilots generally wanted quicker and clearer access to RTA functions and information on the MCDU. Most pilots thought that the EFB design was not particularly supportive of the RTA operation, expressing several suggestions for its iteration. Each design is discussed in turn.

Graphical Flight Planner

As the RTA is a time-based operation, pilots generally wanted to have the current time displayed in a prominent location, or at least one that was in close proximity to the RTA. This suggests that pilots want to be able to scrutinize and compare current time with RTA (and perhaps with ETA) to assess RTA performance throughout the operation. In terms of RTA data entry, some pilots expressed a desire to enter RTA data via the flight planning display. That is, given the information displayed there in terms of current and future waypoints and progress (including the RTA waypoint), such data entry appeared to represent a natural fit for pilots. Pilots were noted to have to calculate the ETA to the RTA waypoint themselves, and as such they wanted to see the ETA depicted just below or otherwise near the RTA as well.

With respect to the GFP display and symbology design, most pilots were supportive of the "picnic table" which, in concert with the RTA data tag, helped them to maintain their assigned RTA and to detect when there was a problem. However, some pilots thought that the RTA data tag information font was too small or was otherwise difficult to see, and that subsequent visual alert of RTA problems (e.g., "RTA Unable") was likewise difficult to notice. Pilots were noted to desire clearer association and "harmony" with respect to the available RTA information, especially when an RTA was not being met. An example of this would be to not only include character "flashing" in the RTA data tag, but to also include a concomitant color change (e.g., to amber) of the RTA waypoint name in the flight plan listing, and a refresh of the listing to show the name at the top of the list (as in longer flight plans the RTA waypoint information may be off-screen). Another example of this association would be when a pilot selects the RTA waypoint on the moving map, the RTA waypoint would automatically appear or would auto-scroll to the top of the flight plan and, if ownship is on the ground, to additionally depict the RTD needed to meet the RTA.

While not a focus of the evaluation, some pilots wanted to see RTA information integrated into the PFD as well, such as trend arrows adjacent to the speed tape that are tied to the RTA waypoint. Some pilots thought that the GFP should share some functionality with the MCDU, which was familiar to them. In particular, pilots wanted the "what if?" type functionality (e.g., fuel consumption) to assess ETA to other waypoints on the flight plan, and not just the RTA waypoint.

Multifunction Control Display Unit

It should be clear that most pilots of modern aircraft are at least familiar with the MCDU, with many of them having many years of experience using it. Pilots in the evaluation were thus quite comfortable with the MCDU and in using it to perform RTA operations. This comfort clearly influenced many of the pilots, but there were some issues nonetheless. The most oft-repeated comment was the need to "search" for RTA-relevant information or otherwise navigate to it on the MCDU. Most pilots thought that if the RTA information (e.g., progress, problems) is not available on the "main page", it should at least be presented in the scratchpad area of any MCDU screen while the RTA is being conducted, as most pilots prefer to keep another page (and not the RTA page) displayed during operations. Similarly, if ownship is on the ground, pilots preferred to have RTD information on the same page as RTA information (it existed on a separate page in the evaluation).

If the MCDU is to be used for RTA operations, then the procedure to enter RTA data should follow established conventions to guard against the need for excessive training. For example, entry of RTA constraints should follow the same procedure as entering data for crossing restrictions (e.g., waypoints on the left side of the page, and constraints on the right side).

Electronic Flight Bag

Many pilots expressed frustration with the EFB for monitoring RTA performance, and none thought the prototype implemented should be used for RTA data entry. There were several issues with the display, including symbology, font size, colors, and data (e.g., the ETA and RTA value depictions were the same in at least one instance). Perhaps hearkening back to pilots' familiarity with the MCDU, there was some ambivalence to having RTA information on the EFB, as "the MCDU has this information already." Other issues included information occlusion that could only be resolved via pilot manipulation of display magnification, and general cluttering of displayed data and symbology. One feature of the EFB was the "time slider", which allowed pilots to "look ahead" on the flight route at future waypoints and other items of interest. But in so doing, the ownship icon would move to wherever the pilot was looking downstream, suggesting that ownship was much further along the route than it actually was.

Generally, pilots were critical of several display areas of the EFB prototype: the moving map, the layer controller, the information window, and the waypoint list. They also did not like the off-angle viewing required to gather the information needed to assess RTA performance. However, it is important to recognize that the concept of using the EFB to support the RTA operation should not be dismissed – the particular instantiation of the EFB assessed in the evaluation and its design shortcomings disallowed effective investigation of its utility for this purpose. Thus, future investigations of a redesigned and revised EFB (that builds on the data gathered in the current evaluation) should be conducted to assess its capability to support RTA operations.

Consideration of Procedures Related to TBO

Here, pilots' impressions of the overall RTA negotiation process are used as an example of the need for consideration of the processes and procedures themselves, in addition to the systems being utilized.

Pilots' comments during the evaluation and on the post-evaluation questionnaire indicated that the interaction with ATC should be an open dialogue. This idea can be thought of as pilots and ATC working together directly to find an acceptable RTA clearance. It is easy to see how this could be preferred to other potential methods of interaction. For example, even though controllers can have a good idea of aircraft performance limitations, it would not be efficient for them to simply keep proposing RTA clearances until they receive a "WILCO" from the flight deck. This indicates that the sharing of data between the flight deck and ground systems is critical for efficient trajectory negotiations. Pilots identified several potential flight deck features that could assist in this negotiation (e.g., the ability to preview proposed flight plan changes to check for feasibility), but the negotiation process itself ultimately needs to be evaluated in conjunction with any system prototypes.

This highlights a need for future evaluations to test different TBO procedures (e.g., datalink vs. voice communications, automatic sharing of aircraft performance data vs. pilot-initiated sharing, etc.) along with evaluating system prototypes in the context of actual proposed procedures.

Noted Operational Issues

Safety, Efficiency, and RTA Hierarchy

RTA should be a conversation with options, rather than a hard constraint that is set in stone. Imagine trying to control something four hours away that is in the hands of the weather gods and your (non-union) management at the same time. RTA should be thought of as a conveyor belt: miss one bucket, and there are other possible buckets. Weather gods frown, and air traffic control understands. Get close to an engine setting that burns too much fuel or wears the engine, ATC understands.

Consider the development of procedures that can re-integrate traffic when RTA is lost, but in a way that isn't a punishment (like a holding pattern) or potentially uncomfortable for passengers. For instance, the aircraft can throttle down over a longer route, or accept path stretching.

Departure Time and Arrival Time

Trajectory Management (TM) can happen either before or during a flight. Because the best predictor of arrival time is departure time, TM dealing with RTA must be closely aligned with departure time. If vectoring happens, the capability to meet RTA changes. If weather must be circumnavigated, again the capability to meet RTA may change. The best predictor of an arrival time is the departure time.

Surface RTA

While RTA has been proposed as a clearance element as critical as maintaining assigned altitude, Honeywell recommends approaching this with great caution. Creating additional time pressure in the cockpit to make an RTA is a very new concept, and it is important that it does not engender unintended behaviors to rush to make an RTA.

This is particularly poignant on the ground. JPDO (2009) suggested that TBO is primarily focused on the en route cruise phase, but some conceptualizations of human-in-the-loop RTA on the ground were particularly alarming. While taxiing at "a brisk walk" is almost never observed – some operators could probably state their taxi speeds as a large fraction of V1 – it is probably not a good idea to encourage making particular speed or time targets on the ground, at least until the larger problems of runway incursions, airport surface situational awareness, and even ownship momentum and sheer size awareness are sorted. RTAs on the ground are very particular to equipment mix. Because TBO is relevant to any appropriately equipped aircraft, from general aviation to air transport, while some large aircraft might taxi at 30 knots, other aircraft might be nearly approaching Vso at this speed. Finally, ground RTA puts focus where it should not be, taking attention from orientation, navigation, and head-on-a-swivel awareness, and putting it on speed.

Enroute Trajectories vs. Straight Lines

Currently, RF legs are mostly used in terminal RNP procedures, but certainly could be used for large, curving flight paths taking advantage of smoother air or optimum winds in pressure-pattern flying.

Shared Situational Awareness

Unless they have flight experience, or substantial operational experience, controllers may not appreciate the differences in certain aircraft types (for instance, speed capability differences between a Cessna 152 and a Cessna 414, on descent), particularly if the pilot uses a generic label or an unfamiliar label. But before a controller makes a request, it would be very advantageous to have possible speeds for a group of aircraft already sorted so that clearances are not requested that are unrealistic. Further, autoflight, autothrottle, flight management equipage may all effect trajectory prediction accuracy, as well as basic maintenance of the trajectory.

Optimization and Exploitation of Descent

The Descent phase is interesting because the RTA tasks and hierarchy appear to be changing. Because of this, the pilot may have increased ability to change speed. There might be +/- 50 knots to play with, and perhaps the potential to change RTA by 1 minute between the first fix on a STAR and the IAF.

Abnormal Operations

In general, abnormal operations have not been well researched. For instance, if an aircraft in a flow has an in-flight shutdown, what are the pilot-controller procedures and responsibilities?

Miscellaneous

- Weather. Pilot reports help the National Weather Service improve forecasts of the jet stream, low level wind shear, and turbulence among others. How the FMS blends, updates, and uses uplink and real-time weather data is a major issue, as is understanding optimum winds and their effect.

- Consequences of Accepting Tradeoffs: Safety, Fuel Efficiency, Turbulence, Vmo, Coffin Corner, Winds/Temps.

- Vertical Visualization Problems.

- Self-Referenced Waypoints (e.g., explore a grid or named waypoints for relative waypoint insertion via known waypoints, or referenced to aircraft).

- Traffic Contention - while pair-wise contention may be a first step, contention between three, four, or more aircraft, or consequences to other aircraft from the resolution of an initial pair-wise contention may all be issues.

- Autoflight and Autothrottle Integration with FMS, Geo-reference and Flight-path reference.

- Compression and Distance reduction: While RTA may ensure appropriate time separation between aircraft at a fix, it does not address compression or distance reduction that different aircraft with different desirable flight profiles (top of descent or speed profiles) fly leading up to the fix.

- Interruption management: Interruptions (e.g., renegotiation of RTA) in higher stress environment (e.g., terminal environment) can be more troublesome than in lower-workload environment (e.g., cruise). Interruptions in normal flight deck task management can negatively affect performance on both tasks and procedures being performed and may have negative safety consequences.

Naming Conventions

Honeywell found substantial variability in naming conventions. Names and labels must be consistent because these will be used on the flight deck. The terminology itself should be usable to both the designers and pilots, and have a similarity to the real world. For instance, a "reference business trajectory" makes little sense to either a displays designer, or a pilot. Further, mixing a lateral concept (e.g., RNP) with a temporal concept (RTA) to create "temporal RNP" is sure to confuse. Possible terminology could include:

- RNP: Required Navigation Performance

- ANP: Actual Navigation Performance

– RTP: Required Time Performance

– ATP: Actual Time Performance

– RTA: Required Time of Arrival

– ATA: Actual Time of Arrival

– RSP: Required Speed Performance

– RLP: Required Lateral Performance

– RVP: Required Vertical Performance

Collection of Objective Performance Data

Here, pilots' preferences for potential RTA alerting systems are used as an example of the need for collecting objective performance data.

Several pilots mentioned their opinions of what would be an ideal alerting system when the FMS determines that they aircraft is no longer able to make an RTA (e.g., MCDU scratchpad messages, alerts on the PFD, CAS messages, etc.). Most pilots mentioned a different preferred method or some combination of methods. The pilots identified the need for an appropriate alerting system because any type of "*unable RTA*" message would just be one more stimulus competing for attention in the cockpit. The fact that many pilots said they would prefer different alerting methods highlights the need for objective, performance-based data to determine the effectiveness of these different methods. This variation was also likely associated with biases towards systems they were already familiar with – a point that indicates the need for the evaluation of training methods as well. Any thresholds associated with such alerting systems would also need to be carefully determined to account for misses and false alarms. This is something that can only be done through the collection of objective data.

Pain Points for TBO Integration

Some examples of potential pain points associated with the implementation of TBO that were not directly addressed by this evaluation are discussed here. These include (but are certainly not limited to) getting pilots and airlines to "buy-in" to TBO concepts, the selection of appropriate decision criteria for pilots, and coordinating the information-sharing that is necessary for effective TBO implementation.

Ensuring that both pilots and airlines are supportive of and actively involved in the implementation of TBO is critical. This step includes demonstrating to both pilots and airlines that TBO is operationally feasible (e.g., increasing efficiency while maintaining or increasing existing safety levels) and, perhaps more importantly, economically beneficial. Determining well-defined and easy to understand decision criteria and procedures for pilots is directly related to this. Will pilots be penalized for busting a time constraint the same way in which they may be penalized for busting an altitude constraint? There should be no gray area for pilots when it comes to accepting/rejecting RTA [or other TBO] clearances. There should be no gray area for pilots when it comes to when they must inform ATC of their inability to meet an RTA (or other TBO) clearance. This means that any RTA-related information presented to pilots needs to be completely understood and thresholds for decision-making can be pre-determined by airlines (e.g., providing pilots with appropriate cost index windows). While this might seem to suggest using automation to make accept/reject decisions, it is preferable to find a way to keep pilots engaged in the decision-making process. As mentioned briefly in the previous section, the appropriate method of information sharing needs to be determined as well before final system prototypes can be developed.

Workload Ratings

While the ratings collected using the Modified Cooper-Harper scale could suggest that the EFB prototype was less favorable than the other two prototypes with regard to workload, some potential related issues deserve mentioning.

First, most pilot participants were already familiar with the MCDU or some other similar interface prior to participating in this evaluation. The style of this evaluation did not allow pilots to become formally acquainted with the prototypes and only allowed limited interaction. This could obviously present a potential bias towards systems that are already familiar. Second, the higher workload ratings for the EFB should not be understood to indicate that EFBs in general are inferior for conducting RTA operations. The fact that the three prototypes utilized very different interfaces and interaction techniques (as opposed to comparing similar interaction techniques across different platforms) means that any perceived differences are likely attributable to the design of the prototypes themselves, rather than issues related to the specific platforms. Third, pilots were not performing tasks in a full flight simulation. This meant that the workloads encountered in this evaluation were not comparable to those that would be encountered in an actual flight. Pilots' workload ratings were likely based on what they perceived their workload would have been in an actual flight environment, rather than the workload actually encountered in this evaluation.

Summary

TBO-related flight deck display concepts need to be thoroughly tested in conjunction with any associated novel procedures. In many instances, the interactions between these novel concepts are too complex to be determined in isolation. When dealing with human-automation interaction issues, there is also a need to collect objective data for determining the optimal system configurations. In the preliminary study conducted here, which relied solely on subjective data, displays incorporating the type of information depicted on the GFP appeared to effectively support pilots in the conduct and maintenance of the RTA procedure, and in being aware of when there were problems with the procedure. However, there were some design shortcomings for various display elements that could be iterated to improve RTA performance and awareness further. Pilots should not have to navigate various MCDU pages to enter or retrieve RTA performance information. If the MCDU is to be used as the primary source of RTA information, then the information should be easily accessible and/or constantly displayed throughout the procedure to afford reduced workload and head-down time. Further, any MCDU data entry associated with the RTA should follow established procedures.

The EFB results from the study should be carefully interpreted. In particular, as much of the subjective feedback from pilots regarding the EFB was clearly negative—which suggests that the particular interface design requires iteration—the results should not be interpreted to indicate that the concept of EFB use to support TBO should *itself* be discarded. Indeed, the EFB represents a critical technology to help bridge legacy-equipped aircraft with modern-equipped aircraft for participation in TBO. The capability of EFBs to support TBO should be investigated further toward not only helping to identify appropriate interface design, but to also identify appropriate procedures for its use and (for equipped aircraft) its integration with FMS.

Recommendations: Draft Requirements and Best Practice Guidelines

In a precursor to the present study, proposed TBO procedures as outlined by the FAA's list of TBO Operational Improvements (OIs) were assessed and possible human factors and pilot performance issues were identified (Lancaster et al., 2011). Based on this assessment and issues identification, requirements for display and FMS enhancements were identified to support design of legacy and enhanced systems. In the following tables, these are presented as draft requirements and preliminary best practice guidelines. Where applicable, the findings from the heuristic evaluation are also presented.

Requirements are considered to be a "must-have," without which the system design is incomplete, unusable, or unsafe.

Best practice guidelines are provided when there are multiple ways to implement a design, but a preference exists.

Roles and Responsibilities

Roles and Responsibilities Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
R&R 1. Appropriate roles and responsibilities allocated between humans and automation and air and ground have not been established.	**Requirement 1:** As roles and responsibilities are defined, ensure they are compatible with the basic operational hierarchy – safety, passenger comfort, and efficiency (including TBO efficiency). Accordingly, as automation is assigned more operational authority, it needs to operate under a set of rules that account for the fact that passenger comfort necessarily includes their physiological and emotional experience. For instance, while one trajectory solution might be perfectly safe and highly efficient, it could have the unintended consequence of making the passengers extremely uncomfortable. Therefore, as long as safety is first and is fully accommodated, it is critical that the automation works out a primary safe, smooth and gentle solution that considers the passenger experience in the same way an experienced captain does, even as efficiency is sought in a secondary or balanced manner. Note that freight operations may allow for automation with a different operational hierarchy. For all operations, it is critical to indicate to the crew what the automation is doing *now*, what it will do next, and the general operational assumptions that are driving it. *Source: Honeywell Subject-Matter*	Honeywell Subject-Matter Expert Judgment	104121

Roles and Responsibilities Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	Experts. **Best Practice Guideline 1:** As flight crews are given responsibility in areas previously handled by ATC, do not force pilots to learn new and arcane ATC procedures (e.g., see complex ITP rules). That is, build the rules (e.g., selection of acceptable altitudes) into the design rather than requiring the crew to remember these rules. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 2:** Keep crew informed and involved in TBO process. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 3:** The interaction style used in the heuristic evaluation was conversational versus confrontational. That is, the controller and pilot were working together to determine what was possible given their systems. In the real world, the systems must encourage the ability to say "unable" when it is warranted. *Source: Heuristic Evaluation.*	Pilots were supportive of being able to work with ATC regarding RTA operations. Pilots want to be able to reject an RTA without consequence, and if they cannot make an RTA, there should not be an associated penalty (e.g., reprimand when "busting an altitude").	
R&R 2. Additional flight crew datacomm	**Requirement 2:** Use datacomm as an opportunity for error checking. For instance, automatically uplink the	Honeywell Subject-Matter	N/A

Roles and Responsibilities Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
responsibilities and procedures related to TBO may cause excessive workload and reduce error detection capabilities in some flight phases.	selected runway in the FMS to ATC; if an incorrect runway has been left in from initial perf, it provides the opportunity to correct it prior to departure. Source: Honeywell Subject-Matter Experts. Best Practice Guideline: Make it easy and visible. *Source: Honeywell Subject-Matter Experts.*	Expert Judgment	
R&R 3. If automation promotes a flight plan preference, then the roles and responsibilities for flight crews must ensure that situation awareness is maintained without negatively impacting workload.	**Best Practice Guideline 4:** On the ground and in the air, provide a flight planning system that supports visualization explaining "why" a particular option is preferable. Provide visualization of airspace, weather, traffic and terrain along the planned flight plan. Remember: opaque, powerful automation degrades understanding and cooperation. Pilots need access not only to min / max values, but what is driving them. *Source: Honeywell Core R&D.* **Best Practice Guideline 5:** Provide visualizations of projected active Special Use Airspace and TFRs such that the crew can take the most advantageous route based on time compatibility with airspace usage. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 6:** Provide the ability to monitor progress of flight plan in relationship to time,	Honeywell Subject-Matter Expert Judgment	101103

Roles and Responsibilities Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	airspace, weather, traffic and terrain along the planned flight plan. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 7:** If an EFB is used, then it must be evaluated to ensure acceptable workload, especially if it is the sole source for RTA performance information for a dual-crew flight deck. Note: Space availability dictates that EFBs are usually installed in an outboard location. Because of this, pilots can lose shared situational awareness and collaborative decision making abilities. This can have an overall negative effective on safety and efficiency of operations and care must be taken in selection of which features and functions ought to be supported. Because of level of interactivity that may be associated with an EFB TBO display (e.g., map scrolling, range control, map layers), it is important to determine what procedures and coordination flight crews should follow to support operational safety. *Source: Honeywell Core R&D.*		

Information Presentation (e.g., format, symbology, location, organization)

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IP 1. The requirements for consistency, accuracy, and timeliness of TBO-related information on flight deck displays have not been established.	**Requirement 3:** The TBO system must be accurate and predictable in its resolution to inspire trust and confidence. Widely swinging values and flipping early / late alerts undermine crew confidence in TBO with RTA (e.g., changing RTA estimates during the climb). *Source: Heuristic Evaluation.* **Best Practice Guideline 8:** If multiple RTA windows or precisions are permitted, limit them to 3. For instance, crews have just a few US Standard RNP levels to remember (RNP 0.3, RNP 1.0, RNP 2.0). Provide visualization of the window size. *Source: Honeywell Core R&D.* **Best Practice Guideline 9:** Use consistent colors and icons across various TBO-related information, e.g., if green is selected as a color to indicate it has an RTA constraint, then color code the waypoint on lateral map, vertical map, waypoint list and 3D view (as applicable) all with same color and similar icon. *Source: Heuristic Evaluation.* **Best Practice Guideline 10:** Depict RTA time and	Pilots preferred RTA performance awareness via the "picnic table" symbology in the GFP when compared to similar text-based MCDU and EFB information. The alphanumeric RTA data tag on the GFP received mixed reviews. Pilots liked the color associations between the GFP's "picnic table" symbology and the RTA waypoint on both the lateral map and FPLN waypoint list.	101103 104105

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	current aircraft performance. *Source: Heuristic Evaluation.* **Best Practice Guideline 11:** If an EFB is used in an aircraft equipped with a FMS, then both systems should be integrated such that there is no possibility of flight crew confusion due to inconsistent information display. Source: Heuristic Evaluation.	Pilots indicated that data entry via the EFB, in particular, would be appropriate only if the EFB was integrated with the FMS.	

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IP 2. RTA is provided as more of an ancillary function in the FMS requiring several keystrokes to access, and information to monitor RTA is distributed across several MCDU pages. Thus head-down time and workload in accessing and integrating information is problematic.	**Best Practice Guideline 12:** Implement RTA as a visible element in the flight deck, accessible on the most-used interface that addresses RTA-related information. For instance, in a MCDU implementation, the Flight Plan and Progress pages are displayed frequently and are natural places for a constraint (though available space is an issue). In a GFP implementation, the waypoint list is a visible, natural place for RTA. Consider providing RTA data entry and monitoring information on the first page of the MCDU or, when engaged, the RTA pages automatically occupy the first page. Present RTD information on the same page as the RTA. *Source: Heuristic Evaluation.* **Best Practice Guideline 13:** In GFP implementations, support RTA situation awareness by presenting RTD information on selection of the RTA waypoint. *Source: Heuristic Evaluation.*	Pilots were supportive of providing a clear path for navigation to the MCDU RTA page. Pilots were supportive of using the MCDU "scratchpad" to alert an RTA "unable" condition. When on the ground, pilots preferred that RTD information automatically appear or be readily accessible.	104126

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IP 3. Numerically signed values used in some FMSs for RTA errors may be difficult to interpret. RTA error depicted as either “early” or “late” would be more intuitive to flight crews.	**Requirement 4:** Use “early” and “late.” A minus sign could be interpreted as early, or it could be interpreted as bad. As a side note, generally crews think of early as meaning “good” even though it is not in the TBO application. *Source: Heuristic Evaluation.* **Best Practice Guideline 14:** Include a range of times to meet the RTA based on current performance. *Source: Heuristic Evaluation.*	Pilots preferred to use “early” and “late” instead of numerically signed values for the RTA. Pilots were supportive of providing a range of times within with the RTA can be “met.”	104126
IP 4. Pilots may have difficulty remaining “in-the-loop” in terms of ongoing operations and possible changes to them unless trajectory operations data and information is presented in a more intuitive way.	**Requirement 5:** Standard symbology is needed to support clear understanding of right of way rules and proper maneuvering during conflict. The symbology should be compatible with legacy TCAS systems and standard right-of-way rules and procedures. Sour*ce: Honeywell Core R&D.* **Best Practice Guideline 15:** Provide an easy, direct means to make “what-if” comparisons that can take several variables into account at once (e.g., RTA with one route compared with a different RTA on an alternate route). The method should copy and use the same elements and symbols as the active flight plan, but should give the crew clear confidence that they	Pilots were supportive of decision support capabilities with which to assess options to meet an RTA and to identify options for possible negotiation with ATC.	101103 104105 104127

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	are not currently making any changes, just assessing options. *Source: Heuristic Evaluation.* **Best Practice Guideline 16:** Clearly show when the aircraft is following a closed trajectory, and when it is operating on an open trajectory. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 17:** A secondary flight plan, as implemented in systems today, is too onerous for "what-if" play making. The data entry has to be minimized and the options simplified (e.g., 3 most likely cases) to be used in flight. *Source: Honeywell Core R&D.* **Best Practice Guideline 18:** Develop charting conventions that are biased toward closed trajectories, versus RNAV STARs that end with radar vectors. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 19:** In particular, new symbology may be needed to support dynamic flow corridors (merging, diverging, crossing), which may use traffic not for alerting and avoidance, but sequencing and synchronization. A metaphor of the No Transgression Zone between runways may be an	Pilots were supportive of an auto-completion capability for RTA data entry, similar to that for radio.	

Information Presentation Issue	**Requirement / Best Practice Guideline**	**Heuristic Evaluation Findings**	**FAA TBO OI#**
	appropriate visualization, with traffic and acceptable lane boundaries presented. The lane lines could indicate both when no transgression is allowed, and also where a course change, safe exit, or parallel course is appropriate (e.g., via gore point). Vertical boundaries are also candidates for display during critical operations, and could potentially take advantage of existing TCAS guidance, such as ADI fly-to goalposts. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 20:** To avoid clutter, show the symbology only when it is needed, not full time. *Source: Honeywell Subject-Matter Experts.*		
IP 5. Pilots had difficulty in understanding entire uplinked messages without checking several FMS pages.	**Requirement 6:** Reveal the clearance visually and textually on the persistent flight deck displays. *Source: Honeywell Core R&D.*	Honeywell Subject-Matter Expert Judgment	101103

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IP 6. The amount and type of information depicted for trajectory based operations may cause undue display clutter.	**Requirement 7:** Use existing symbology, such as flight path markers and waypoints to link earth frame of reference with aircraft body acceleration frame of reference. *Source: Honeywell Core R&D.* **Best Practice Guideline 21:** Use a combination of several complimentary views rather than just one. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 22:** Provide the capability to reduce clutter at the pilot's discretion. *Source: Honeywell Core R&D.*	Pilots were supportive of the 3D PFD display symbology. Pilots were supportive of both lateral and vertical views. Pilots were supportive of being able to "zoom in/out" to help reduce clutter.	N/A

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IP 7. Optimal display formats need to be developed to support monitoring and execution of 4D trajectories, and that simultaneously support flight crews' ability to satisfy mission goals (e.g., safety, passenger comfort, efficiency).	**Best Practice Guideline 23:** In addition to showing a single RTA that is becoming unachievable, show meaningful (in terms of precision) increments prior to the RTA that help explain where the RTA is doable, where it becomes undoable, and why. *Source: Heuristic Evaluation.* **Best Practice Guideline 24:** Consider some display of probability that displays a 4D TBO's resistance to change (e.g., ATC may not be open to trajectory negotiation if the current trajectory is key to current flow management needs), goodness of the estimate, etc. *Source: Honeywell Subject-Matter Experts.*	Pilots were supportive of information that helps them to identify what actions may impact RTA performance.	Multiple
IP 8. TBO information location and distribution across displays need to be identified to support effective pilot performance.	**Requirement 8:** Continue to show textual information. Doing away with text is not an advancement considering the clear and direct information that text conveys. TBO should be shown graphically, textually, and with features that support previewing and explanation ("why"). *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 25:** While a single new display (e.g., 3D volumetric visualization) might be possible in a future iteration, use the basics that already exist: a	Pilots were supportive of integrating RTA information into the PFD (e.g., identifying an RTA waypoint on a 3D waypoint display, "RTA mode" indication).	N/A

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	tactical PFD, ideally flight path based and with synthetic vision, a tactical lateral map display, a strategic lateral map display, a vertical situation display, and a waypoint list. Amongst these formats which exist at least in a basic form in many air transport and general aviation flight decks, crews are able to do three things: analyze (break the x-y-z-t problem apart into x-y, x-z, and x-y-t), synthesize (see the big picture), and evaluate (make the judgment call). The scan between the displays is analogous to a primary – secondary instrument scan under varying flight phases. Several instruments with supporting insight into the situation are often better than a single view that tries to accomplish everything. *Source: Honeywell Core R&D.* **Best Practice Guideline 26:** Provide visual anchor points to assist pilots in relating elements from one display view point to another. The use of similar or same colors, icons, font, and other items across display areas will be incorporated to facilitate use and rapid transition between the displays. *Source: Honeywell Core R&D.* **Best Practice Guideline 27:** Where control/input of		

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	TBO information is required, co-locate supporting TBO information (e.g., don't make pilots go to other displays while entering information on a MCDU page). *Source: Heuristic Evaluation.*		
IP 9. It is important to identify display symbology that supports speed modulation, including how pilots can realize their assigned RTAs in situations when their aircraft is off-track and/or if they are ahead of or behind their RTA.	**Requirement 9:** Displays should provide integrated speed target bugs on the PFD that indicate required speed needed to make the arrival time. *Source: Heuristic Evaluation.* **Best Practice Guideline 28:** Displays should provide a thrust director that indicates thrust needed to achieve desired airspeed. This is particularly valuable in aircraft not equipped with an autothrottle system. *Source: Heuristic Evaluation.* **Best Practice Guideline 29:** Give the crew awareness of the flow. That is, show the available positions on the conveyor belt where the crew could possibly fit their flight should an RTA become unattainable. This will encourage the "unable" conversation rather than engendering potentially risky behavior to meet an incontrovertible time. However, if no positions are available, the crew should have alternatives readily provided so that they can consider all the data before	Pilots were supportive of incorporating RTA information into the PFD (e.g., RTA "speed bug", thrust director "RTA mode"). Pilots were supportive of providing alternatives for assessment when an RTA might be undoable.	102146

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	making a decision. *Source: Heuristic Evaluation.* **Best Practice Guideline 30:** RTAs can naturally increase workload (consider the NASA TLX – temporal demand is a major scale), introducing a new element of time pressure. It is critical that this time pressure does not lead to rushing and task shedding, thus emphasizing the need to have RTA options that are accurate and reliable. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 31:** Consider providing RTA monitoring and control information integrated into the PFD (e.g., speed bug when RTA operative) and/or on the Mode Control Panel. *Source: Heuristic Evaluation.*		
IP 10. Textual information does not appear to be sufficient to support 4DT – it is expected that a balance will need to be achieved between text and graphical depictions of 4D information.	**Best Practice Guideline 32:** For 4D TBO, use graphical and textual together. While textual information isn't preferable to combined graphical – textual displays for the temporal dimension, it is surprisingly helpful in making a call, and might be appropriate on its own for only the RTA if more carefully integrated with visible MCDU pages. While crews liked graphical depictions, textual early and late times were frequently	Pilots preferred RTA performance awareness via the "picnic table" symbology in the GFP when compared to similar text-based MCDU and EFB information. However, some pilots were supportive of the MCDU	N/A

Information Presentation Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	referenced in deciding if an RTA was possible. *Source: Heuristic Evaluation; Honeywell Subject-Matter Experts.* **Best Practice Guideline 33:** Flight planning services should present proposed flight plans not only as a static, coded text block, but as an animation or group of potential animations that can be visualized, selected, and requested 2 hours before flight time, and up to engine start time. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 34:** A depiction of a flight plan graphic adjacent to a waypoint list that includes constraints facilitates cross-comparison referencing. Additional use of a data block inset on the map may provide high glance value for progress on next waypoint constraint. *Source: Honeywell Subject-Matter Experts.*	"scratchpad" display of RTA "unable" information. The alphanumeric RTA data tag on the GFP received mixed reviews.	

Information Content

Information Content Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
IC 1. Neither the functionality of the Advanced FMS nor its interface was detailed in terms of the TBO negotiation process; hence the information requirements in terms of the human factors and pilot performance issues related to envisioned negotiation processes are unknown.	**Best Practice Guideline 35:** Crews should be provided feedback on not only *what* TBO procedures are required and how well they are being followed, but also *why* the procedures are required, in visual terms if at all possible. In addition to satisfying a basic human – and especially, pilot – need for rationality, seeing and learning why something is being requested helps to teach the underlying rules, prepares the crew for future operations in NextGen, and further lets them contribute to possible alternative solutions. The need for "why" should also go the other way, with ATC apprised of safety, turbulence, fuel constraints. Provide insight, not opacity. *Source: Heuristic Evaluation.*	Pilots were supportive of being provided with information about why they are being asked to do things. They thought that more information might help them to assist ATC and to proffer alternatives.	104105
IC 2. Flight deck information that assures integration between air and ground as a cohesive system rather than two disconnected subsystems	**Requirement 10:** Populate ATC and flight deck systems with known likely constraints. For instance, if an RTA request would require a descent above M_{mo}, then the controller should be advised prior to making such a request. *Source: Honeywell Subject-Matter Experts.*	While pilots generally agreed that ATC is aware of their aircraft's performance constraints, they also wanted to be informed if any ATC directives impact aircraft capabilities.	101103 104105

Information Content Issue	**Requirement / Best Practice Guideline**	**Heuristic Evaluation Findings**	**FAA TBO OI#**
has not been identified.	**Best Practice Guideline 36:** Harmonize the technological development of aircraft innovations with the technological development of airspace systems. Take a systems perspective, including humans on the flight deck, humans in dispatch, humans in maintenance, humans in air traffic control. *Source: Honeywell Core R&D.*		
IC 3. Managing aircraft performance to meet the RTA times and locations was more difficult given the lack of feedback. Pilots indicated that they required ground speed, the distance remaining between checkpoints, and throttle up/down indicators information to adequately perform this task, but these information requirements have not been validated.	**Best Practice Guideline 37:** Provide crews performance-on-RTA in both tactical aviate and strategic navigate views. For instance, a thrust director (in concert with speed bugs on the airspeed tape) on the PFD could be used as a near-term cue in correlation with a farther-term ETA and RTA over a lateral map or waypoint. Use caution, however, as encouraging throttle motion may not be the best option; a different altitude might allow safer passage around weather, a smoother ride, or more efficient winds. *Source: Heuristic Evaluation.* **Best Practice Guideline 38:** Provide the current time in a prominent location to support pilot assessment of RTA and RTD information.	Pilots were supportive of the "picnic table" RTA- and speed-referenced symbology, and also the concept of an RTA-referenced thrust director on the PFD. Pilots were also supportive of any flight route information that might benefit them but which would still meet RTA constraints (e.g., different altitude for a smoother ride). Pilots thought that the current time should be displayed. Pilots thought that ETA information should be depicted near the RTA	104121

Information Content Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	Source: Heuristic Evaluation. **Best Practice Guideline 39:** Consider depicting ETA information alongside or directly beneath RTA information. Also, consider depicting ETA information for each waypoint along the route prior to the RTA waypoint. *Source: Heuristic Evaluation.* **Best Practice Guideline 40:** When using time units, use appropriate rounding and unit measure. E.g., instead of using "-1.52" use "Late 1:30". Unit resolution should be appropriate to task e.g., it is unforeseeable that milliseconds would ever be appropriate for TBO task. *Source: Heuristic Evaluation.*	information, and would also prefer to have ETA for each waypoint along the flight route. Pilots wanted to see RTA values to be presented in meaningful units.	

Controls / Input Methods

Controls / Input Methods Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
CIM 1. In this study there was a requirement to use yoke controls for MFD manipulation. The most usable methods for display manipulation and information input depend on types of inputs required, the location of input device, susceptibility to input errors, etc., and these issues have not been thoroughly addressed for TBO-related inputs.	**Best Practice Guideline 41:** Use controls and displays already accessible to the pilot, and within the flight deck design philosophy, so long as those controls can deliver the intended function of the TBO design. For instance, crews believed that the 1/6 "Cross" dialog box in the Graphical Flight Planning condition was a natural place for time constraint entry, in concert with the already-certified trackball cursor control device. *Source: Heuristic Evaluation.* **Best Practice Guideline 42:** Implement RTA in such a way that general aviation aircraft without an autothrottle can participate in the system. Consider flight directors, flight path markers, speed deviation tapes, and thrust directors for these applications. *Source: Honeywell Subject-Matter Experts.*	Pilots were supportive of using a cross-dialog box to enter RTA information in the GFP display.	N/A
CIM 2. How to best support what appear to be relatively fine	**Best Practice Guideline 43:** Do not turn the pilot into a router. If the pilot has to either move information from one place to another, or	Honeywell Subject-Matter Expert Judgment	N/A

Controls / Input Methods Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
manipulations of displayed information associated with TBOs across all flight conditions (including turbulence) has not been evaluated for potential errors and task times.	remember information even as other data is consulted, something is wrong. *Source: Honeywell Core R&D.*		
CIM 3. The use of an input device to control displays with TBO information has not been evaluated in terms of how and where the input device could best be integrated into the flight deck.	**Best Practice Guideline 44:** On current generation flight decks, use existing generic input devices such as trackball, touchpad, and force-rate transducer cursor control devices. Crews already expect to use these devices within the operational philosophy of the flight deck, so design for TBO should fit within this existing philosophy. *Source: Honeywell Core R&D.* **Best Practice Guideline 45:** Unless an EFB or tablet already exists in the flight deck and is used for navigation situational awareness, and further, unless the forward displays or MCDU simply cannot be upgraded to support TBO, reconsider adding an EFB just to support TBO. EFBs draw attention down and away to a wholly	The capabilities of an EFB touchscreen to support RTA operations should be evaluated. Pilots were not supportive of an outboard EFB location as the sole source with which to monitor RTA performance.	N/A

Controls / Input Methods Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	new location, misaligning the eyes and inner ear with the direction of flight. Additionally, the outboard location of EFBs does not facilitate collaborative decision making or cockpit resource management. *Source: Heuristic Evaluation.* **Best Practice Guideline 46:** As tablet devices make their way onto the flight deck, it is important that they are made to match the flight deck and illuminate more of the current situation suing the common, flight deck philosophy frame of reference. Any EFB should be confirmatory guidance rather than primary guidance. *Source: Honeywell Subject-Matter Experts.* **Best Practice Guideline 47:** Consider autocomplete support for pilots when entering RTA data. *Source: Heuristic Evaluation.*		

Procedures and Training

Procedures and Training Issue	**Requirement / Best Practice Guideline**	**Heuristic Evaluation Findings**	**FAA TBO OI#**
P&T 1. If the aircraft designated to maneuver does not do so within a specified period of time or makes an inappropriate maneuver, then contingency procedures will be invoked requiring the other aircraft to execute an avoidance maneuver. The safety of such back-up situation-contingent procedures needs to be evaluated.	**Best Practice Guideline 48:** Cautiously consider the inclusion of TCAS auto-maneuvering functions for TBO, but be excessively alert for potential violations of flight deck philosophy and pilot-in-command authority and responsibility. Further, be alert to varying autoflight / autothrottle equipage which may preclude coordinated auto-maneuvering between aircraft. *Source: Honeywell Core R&D.*	Honeywell Subject-Matter Expert Judgment	102148 108105 108106
P&T 2. Pilot interface and training requirements to support awareness and management of these FMS “speed violations” need to be identified.	**Requirement 11:** Procedures need to clearly define under what circumstances (timing, thresholds) a pilot needs to inform ATC when the aircraft can no longer attain an RTA clearance limit. Procedure needs to be understood on what the ramifications are for “busting” an RTA, e.g., is it compatible to potential consequences of an	Pilots thought that training will be required to understand RTA operations and associated symbology, and particularly how they may impact established schemas. Pilots want RTA speed information to be clear, including how speed limits	104121

Procedures and Training Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
	altitude bust. *Source: Heuristic Evaluation.* **Best Practice Guideline 49:** Systems should not require crews to remember new numbers and acceptable procedures. Rather, the procedure should be designed into the interface such that the design supports the correct procedure and precludes the incorrect procedure. *Source: Honeywell Core R&D.* **Best Practice Guideline 50:** Ensure that pilots are aware that RTA speed limits override the FMS PERF speed values, and that awareness of autopilot modes is supported. *Source: Heuristic Evaluation.*	relate to FMS PERF values, and how autopilot modes affect RTA monitoring tasks. Pilots want to know precisely what operational conditions warrant communications with ATC.	
P&T 3. The more complex strategic trajectory clearances that form the basis of TBO, such as arbitrary route and/or altitude changes, have not been fully explored and	**Requirement 12:** Provide for a sequence that includes "what-if," why, consequences / probability, and leads to a decision, "I can…" *Source: Heuristic Evaluation.*	Pilots were supportive of providing alternatives for assessment when an RTA might be undoable.	101103 104105 104121 104126

Procedures and Training Issue	**Requirement / Best Practice Guideline**	**Heuristic Evaluation Findings**	**FAA TBO OI#**
thus need resolution.	**Best Practice Guideline 51:** RTA accept/decline determinations should be supported via decision support tools that help pilots to assess Cost Index, fuel, weather, and other nominal indices. *Source: Heuristic Evaluation.*	Pilots were supportive of decision support tools to help them assess RTAs.	
P&T 4. Clearances requesting horizontal changes took longer for pilots to understand and execute than did vertical changes.	**Best Practice Guideline 52:** Provide visual information that effectively utilizes lateral and vertical displays to support timely assessment and execution of horizontal change clearances. *Source: Honeywell Core R&D.*	Honeywell Subject-Matter Expert Judgment	N/A
P&T 5. Need to identify how best to objectively measure whether procedures and equipment are suitable, the expected benefits to users in an environment of mixed-equipage, and how to design operations within failure and	**Best Practice Guideline 53:** If an interface looks like it was designed by an engineer (e.g., the labels require a look up table), it probably was also designed for an engineer. Displays that mimic a HP scientific calculator have no place in the cockpit. *Source: Honeywell Subject-Matter Experts.*	Honeywell Subject-Matter Expert Judgment	N/A

Procedures and Training Issue	**Requirement / Best Practice Guideline**	**Heuristic Evaluation Findings**	**FAA TBO OI#**
uncertainty modes.			
P&T 6. Further research is needed on managing the time frame of trajectory negotiation.	**Best Practice Guideline 54:** Permit temporal rehearsal that includes visualization of "what happens if I accept this?" *Source: Honeywell Subject-Matter Experts.*	Honeywell Subject-Matter Expert Judgment	102114
P&T 7. In the event of automation failure, pilots may need systems that support recovery via manual control in a precision flight environment (e.g., 0.1 RNP).	**Best Practice Guideline 55:** Provide both near-view flight director cues ("turn this way now") and far-view natural world views ("I'm driving you to this point-in-space"). A flight path marker based synthetic or combined vision system is a possible way to implement this practice. *Source: Core Honeywell R&D.*	Honeywell Subject-Matter Expert Judgment	104107 104121 104125

Human Performance

Human Performance Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
HP 1. New types of pilot errors and human performance issues could occur in receiving, understanding, and responding to TBO-related data link messages.	**Best Practice Guideline 56:** A picture is worth 1,000 words. Provide the data link message in summary textual form, and further show its meaning and consequence in position, altitude, speed, time or other relevant terms within the existing flight deck design philosophy. *Source: Core Honeywell R&D.*	Honeywell Subject-Matter Expert Judgment	N/A
HP 2. Even with a precise RTA calculation method, considerable time of arrival error was found.	**Best Practice Guideline 57:** Use symbology that clearly conveys RTA performance. *Source: Heuristic Evaluation.*	Pilots were supportive of the “picnic table” RTA- and speed-referenced symbology,	102146
HP 3. The flight tests addressed 4DT feasibility, not whether human performance is supported adequately in a range of situations. It is not assured that 4DT can be performed without errors or delays in response times in high workload and other	**Best Practice Guideline 58:** RTA performance and display design should be assessed in a variety of off-nominal conditions. *Source: Honeywell Subject-Matter Experts review.*	Honeywell Subject-Matter Expert Judgment	N/A

Human Performance Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
situations that can be challenging to flight crew performance.			

Workload

Workload Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
W 1. In situations of high traffic operations and high pilot workload, relative waypoint insertion is probably impractical once in the TRACON with voice communication as the limiting factor for data transmission. If using published procedures, then pilot selection of the appropriate procedure requires scrolling through multiple FMS pages, which poses a significant workload issue and risk for error.	**Requirement 13:** Support acceptable workload by placing RTA pages in an easy to access location that minimizes head down time along with button presses. *Source: Heuristic Evaluation*.	Pilots wanted to be able to access MCDU RTA information quickly, and were supportive of being notified about an RTA "unable" via the MCDU "scratchpad."	108209
W 2. Surface TBO displays increased workload, the number of speed commands was too high, and pilots needed to be "eyes in" and away from	**Best Practice Guideline 59:** Position RTA symbology in the pilots' forward Field of View. Other locations conveying similar information should not be the primary source of RTA symbology (e.g., outboard EFB).	Pilots were not supportive of having to go "head-down" for any appreciable length of time when conducting RTA operations.	102146

Workload Issue	Requirement / Best Practice Guideline	Heuristic Evaluation Findings	FAA TBO OI#
the out-the-window view, possibly requiring increased crew coordination.	*Source: Heuristic Evaluation.*		
W 3. Assessments of RTA have required significant head-down time on the MCDU in order to monitor RTA progress.	**Best Practice Guideline 60:** Consider integrating RTA information into existing PFD and/or panel locations. *Source: Heuristic Evaluation.*	Pilots were supportive of integrating RTA information into panel displays to support operations monitoring in the forward field-of-view.	102146
W 4. Text-based FMS can result in increased head-down time and associated workload.	**Best Practice Guideline 61:** The MCDU should not be the primary source of RTA information/progress. *Source: Heuristic Evaluation.*	Pilots were not supportive of having to go "head-down" for any appreciable length of time when conducting RTA operations.	N/A
W 5. Clearance information distributed on different MCDU pages and manual loading of TBO clearances can cause excessive workload and data entry errors.	**Best Practice Guideline 62:** Consider presenting RTA information on the first MCDU page when RTA operations are in effect. *Source: Heuristic Evaluation.*	Pilots were supportive of having the RTA page "up front"/as the first MCDU page when conducting RTA operations.	101103

Conclusion and Next Steps

During Phase 1 of the study, Honeywell reviewed literature on TBO procedures and identified possible human factors and pilot performance issues relevant to the evolution to 4D TBO operations during a heuristic evaluation. Three interfaces were adapted: an MCDU, an integrated GFP and an EFB. The study looked at how well the proposed interfaces supported pilot decision making, how easy they were to learn, their effect on self reported workload, and the way in which the information was presented (including aesthetics, was functional behavior clear, and did it include the desired functions). In general, pilots thought the MCDU and integrated GFP implementations supported good RTA-related decision making, while the EFB prototype received less favorable feedback. Criticisms from pilots of the EFB implementation included comments on format layout, clutter, size, color and readability. The study participants provided direction for improving the EFB design and their feedback should be revisited along with further investigation into overall suitability of the EFB to support TBO operations. Based upon the results of this heuristic evaluation, it is not possible to isolate the design of the prototype from the functionality an EFB could provide to crews in execution of TBO procedures.

Overall this study provided an opportunity to explore the TBO concept of operations with pilots and identify desirable display features and characteristics. Results of the heuristic evaluation led to draft requirements and best practice guidelines. These should be viewed as draft in nature and the intent would be to refine and improve them as additional data is collected from larger pilot sample with improved prototypes. In addition, there are research questions related to TBO procedures that need to be further explored. For instance, one of the primary safety concerns of using RTAs is the potential distance reduction between two in-trail aircraft. A loss of minimum spacing is possible, even if both aircraft meet their assigned times. While each aircraft is controlling to a specified Time of Arrival at a fix, there is potential distance reduction in separation prior to that fix because of different speed strategies (e.g., heavy vs. medium sized aircraft) to meet the specified time and different speed control algorithms providing closed loop control to correct for time errors (e.g., different forecast winds and temperatures) (Smedt and Klooster, 2011).

In Phase 2, we plan to use the results from the heuristic evaluation to refine the prototypes and conduct human-in-the-loop simulator evaluations using legacy equipment (i.e., autothrottle/ autopilot/ flight director and flight-management system [FMS]) and enhanced equipment. The more formal pilot-in-the-loop evaluations will use selected TBO scenarios, chosen based on their potential to challenge the capability of the operator to perform safely. Pilot performance metrics include maintenance of flight indices, time, errors, workload, and situation awareness. In summary, the recommended next steps are:

- Refine display and FMS enhanced prototypes based upon results of the heuristic evaluation. In particular, revisit the EFB design by incorporating (as appropriate and to the extent possible) symbology, colors, fonts, and interaction capabilities from the GFP that were identified as useful to pilots.

- Design pilot-in-the-loop experiment to assess pilot performance during TBO with legacy and enhanced systems. Tasks include experiment design, scenario and test conduct performance capture materials and software.

- Conduct pilot-in-the-loop experiment with varied sample of pilots (e.g., FAA, test and line pilots). Perform data analysis and report results.

- Refine best practice guidelines for cockpit system enhancements to support TBO.

As part of the last two steps, follow-on results are expected to identify potential human factors and pilot performance issues including sources of crew blunders in legacy and enhanced display and FMS systems. The pilot-in-the loop evaluation will be leveraged to recommend requirements and best practice guidelines for cockpit system enhancements to support TBO.

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Appendix A: Briefing Guide and Scenarios

Human-in-the-Loop Evaluation of Selected NextGen TBO Scenarios

Investigator Guide

– Set Display Condition Per Counterbalance: 1 hour before sim run or upon completing trial

MCDU Condition Display System Setup

PFD	Standard Blue/Brown, No SVS, No FPM, North Up
Lateral Map	ATMap, Aircraft Centered, Heading Up, with Flight Plan
Center Touchscreen	FMS
Side Touchscreen	Off / Swing Away / NO EFB

EFB Condition Display System Setup

PFD	Standard Blue/Brown, No SVS, No FPM, North Up
Lateral Map	ATMap, Aircraft Centered, Heading Up, with Flight Plan
Center Touchscreen	FMS
Side Touchscreen	EFB

GFP Condition Display System Setup

PFD	SVS with 3D Waypoints, Track Up, Terrain On, FPM On
Lateral Map	EASy Lateral Map with Waypoint List and VSD, North Up
Center Touchscreen	FMS
Side Touchscreen	Off / Swing Away / NO EFB

– Select SCENARIO File in MS FlightSim per Counterbalance

Bozeman-Phoenix	TBO KBZN-KPHX
Detroit-Dulles	TBO KDTW-KIAD
Phoenix-Miami	TBO KPHX-KMIA

- Select FMS SCENARIO File to match MS FlightSim. Close and Restart MCDU FMS every time. If FMS fails, right click on APU in menu bar. Start FMS first, then APU.

FMS, Check Pos Init and Complete Perf Init

On FMS, Select PERF, Select NEXT until reaching page 5/5
Enter 20000, line select to FUEL
Enter 1000, line select to CARGO
Enter 6, line select to PASS/@ LB

FMS, Select Flightplan. NAV > FPLN LIST > (then one of the below)>FPL SEL>ACTIVATE

Bozeman-Phoenix	T1-BZN-PHX
Detroit-Dulles	T2-DTW-IAD
Phoenix-Miami	T3-PHX-MIA (T4 file will be used later in scenario)

Welcome Participant and Give Consent Form.

Familiarization

Just before first testing (and only the first testing) of a condition (MCDU, GFP, EFB), point out the salient per-interface features from printout (following pages, and separate EFB Guide). With MCDU, also describe how to interact with system since it will be used as both a control and a display, but assure participant that you will be right there if they need any help.

Before beginning test, ask the participant to fill out a practice Modified Cooper-Harper.

RTA Entry (For Reference Only)

MCDU

- RTA Page
- Select PERF
- Select NEXT to go to page 2/2
- Use Line Select Key to select RTA
- Enter RTA Fix
- Enter RTA between the early and late values (WAIT until early and late values refresh)
- Enter RTA that is before early value (WAIT until you receive UNABLE RTA AT _____)
- Select CLR
- Enter RTA that is after the late value (WAIT until you receive UNABLE RTA AT_____)

RTD LSK (Used in PHOENIX SCENARIO ONLY) – will be ASAP unless waiting is required.

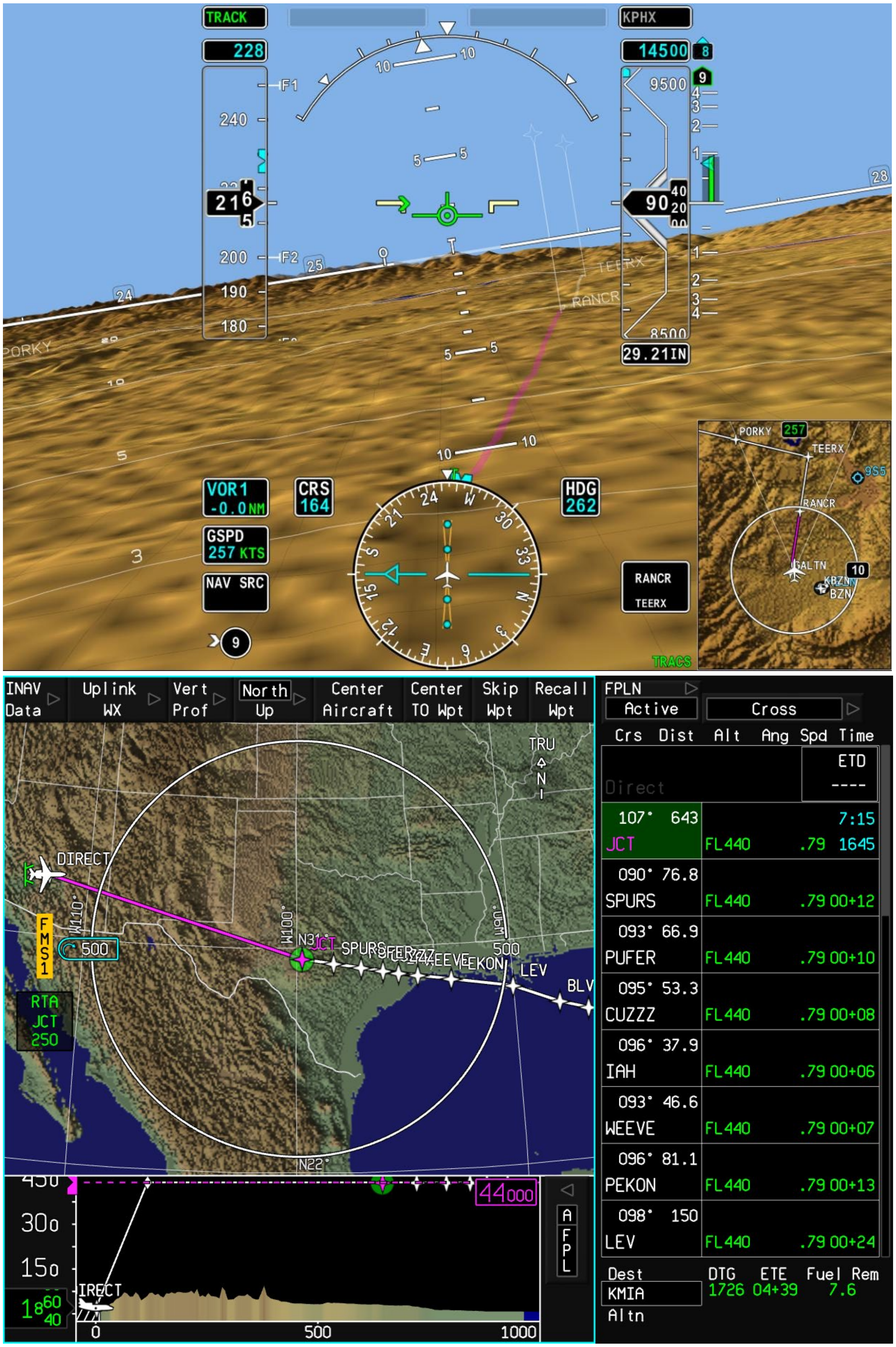
GFP

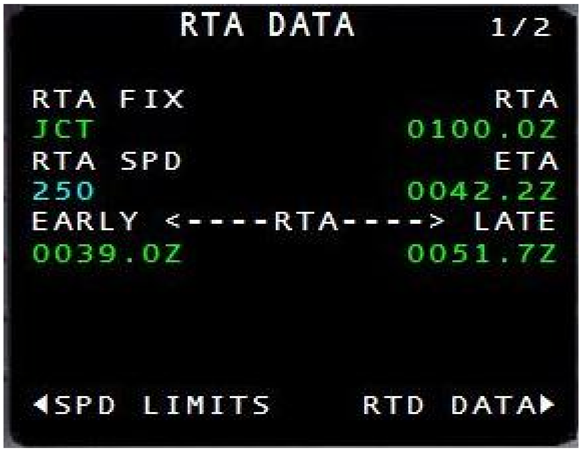
- MCDU – To get to RTA page…Select PERF…
- MCDU - Select NEXT to go to page 2/2
- MCDU - Use Line Select Key to select RTA

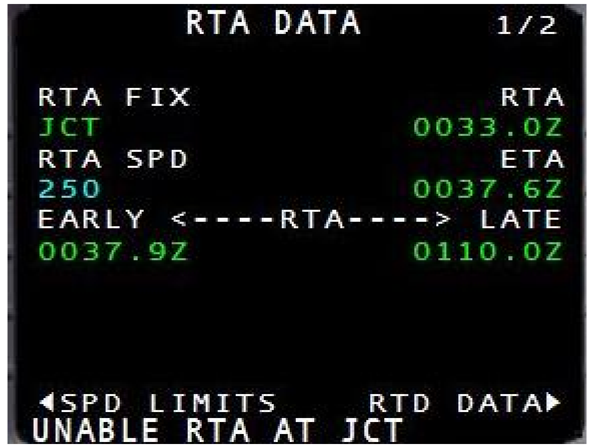
- MCDU - Enter RTA Fix, show symbology, box, graphics on Lateral Map, waypoint list.
- MCDU - Enter RTA between the early and late values (WAIT until early and late values refresh), **show symbology, box, time range, picnic table, graphics on Lateral Map, waypoint list**
- Enter RTA that is before early value (WAIT until you receive UNABLE RTA AT _____), **show symbology, box, picnic table, graphics on Lateral Map, waypoint list**
- Select CLR
- Enter RTA that is after the late value (WAIT until you receive UNABLE RTA AT_____), **show symbology, box, picnic table, graphics on Lateral Map, waypoint list**

RTD LSK (Used in PHOENIX SCENARIO ONLY) – will be ASAP unless waiting is required.

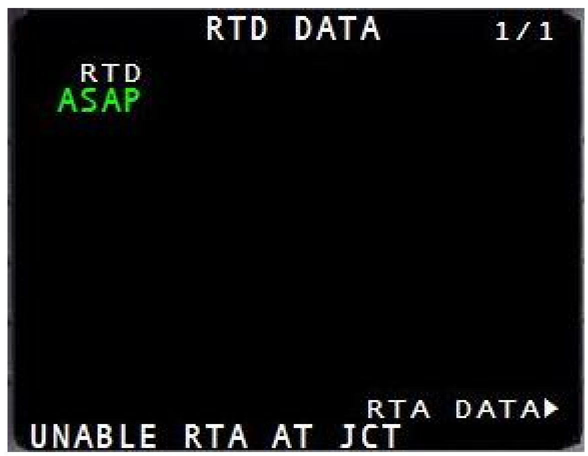
Graphical Format Familiarization




RTA DATA 1/2
RTA FIX RTA
JCT 0100.0Z
RTA SPD ETA
250 0042.2Z
EARLY <----RTA----> LATE
0039.0Z 0051.7Z
◄SPD LIMITS RTD DATA►


RTA DATA 1/2
RTA FIX RTA
JCT 0033.0Z
RTA SPD ETA
250 0037.6Z
EARLY <----RTA----> LATE
0037.9Z 0110.0Z
◄SPD LIMITS RTD DATA►
UNABLE RTA AT JCT


RTD DATA 1/1
RTD
2326Z
RTA DATA►


RTD DATA 1/1
RTD
ASAP
RTA DATA►
UNABLE RTA AT JCT

Bozeman to Phoenix

RECHECK COUNTERBALANCE SHEET
SET DISPLAY CONDITION
KBZN-KPHX (MS FlightSim) Check POS INIT, Complete PERF INIT and T1-BZN-PHX (MCDU)

Flight Plan
KBZN.TEERX1.DBS.J9.FFU.J11.DRK.COYOT2.KPHX

Runway	KBZN RWY 12
RNAV Departure	GALTN.RANCR.TEERX.PORKY.DBS (TEERX1.DBS)
Enroute	J9.FFU.J11.DRK
Arrival	HATRK.MAIER.WEBAD.COYOT.BRUSR.MAHEM.PXR (DRK.COYOT2)
Approach / Expect	UPNIW (IAF from PXR) RNAV GPS Y RWY 7L KPHX

Participant Instructions

This scenario begins with your aircraft, Citation 789H, enroute from Bozeman Montana to Phoenix. You took off from Bozeman on Runway 12. You've completed the TEERX1.DBS RNAV Departure as published, and are cleared as filed all the way to Phoenix. Right now you have just passed TEERX and are proceeding in a climb direct PORKY.

Show the flight plan in the appropriate interface (MCDU, GFP, or EFB) including RTA waypoint.

I will play the role of air traffic control. If at any time you would initiate a conversation with ATC, please do. For instance, if you find that you need an amended clearance because you are unable to make an RTA, please make that call as you would in the real world.

Note that your system is set up in a fully automatic mode once the autoflight is engaged. That is, the autothrottle will try to close on the RTA.

In addition to playing your role as pilot, please feel free to come out of character and discuss your thoughts on the interface or interaction at any time. That is, please use the scenario as a means to imagine this system in the real world, and also give us your expert opinion all along the way.

Do you have any questions?
Unpause simulator

Check AP Modes Engaged: SPEED HDG SEL ALT HOLD

Bozeman to Phoenix ATC Sequence

Enter RTA Waypoint for the participant in the MCDU.

Select a doable RTA but close to the early value

Citation 789H, Cross BRUSR at __________.

Citation 789H enters RTA clearance into FMS.

Winds should make RTA undoable. If they do not, enter an RTA that is too early to force RTA Unable.

If pilot does not respond to unable RTA within 1 minute after unable RTA alert, point out the symbology.

If pilot says unable BRUSR, then
Citation 789H, say ETA at BRUSR.
(response)
Citation 789H, Cross BRUSR at (the ETA value)

Pilot enters RTA in MCDU, looks at display on display interface

End of Scenario, PREPARE NEXT SIM CONDITION, give Participant Workload Instrument.

Post-Scenario Questions

How would you like to be alerted or advised when an RTA is becoming undoable due to changing conditions?

What sort of conversation would require between ATC and the crew, and how would you like the interaction with ATC to go when negotiating an RTA?

How do you think data link will change the nature of this conversation?

How advantageous is it for this alerting to be delivered early?

Would you like information on why the RTA is becoming undoable?

What decisions do you need to make when accepting or rejecting an RTA?

What information and comparisons do you wish you had available to make these decisions?

Detroit to Dulles
RECHECK COUNTERBALANCE SHEET
SET DISPLAY CONDITION
TBO KDTW-KIAD (MS FlightSim) Check POS INIT, Complete PERF INIT and T2-DTW-IAD (MCDU)

Flight Plan
KDTW.DJB.J34.AIR.J34.BUCKO.ESL.SHNON2.KIAD

Runway	KDTW RWY 21L (Direct to DJB, No SID)
Enroute	DJB.J34.AIR.J34.BUCKO
Arrival	ESL.DRUZZ.RAZZZ.SHNON.ROYIL.KEWPY.ELISN.MATTC (SHNON2 Arrival)
Approach / Expect	CRVER (Feeder fix) RNAV GPS Y RWY 19C KIAD

Participant Instructions

This scenario begins with your aircraft, Citation 789H, on Runway 21L and awaiting clearance from Detroit Metro Airport, Michigan to Dulles, Virginia. After takeoff, you've been told to expect direct Dryer VOR (DJB), and then cleared as filed all the way to DRUZZ, the RTA metering fix. In fact, in the spirit of end-to-end RNAV operations, ATC has already told you to expect RNAV GPS Y Runway 19C assuming no major changes in traffic or weather.

Show flight plan in appropriate interface (MCDU, GFP, or EFB) including RTA waypoint, DRUZZ.

I will play the role of air traffic control. If at any time you would initiate a conversation with ATC, please do. For instance, if you find that you need an amended clearance because you are unable to make an RTA, please make that call as you would in the real world.

Once we unpause and you are ready to fly, release the parking brake, here, advance the throttles, and rotate at Vr. I'll call positive climb, you call gear up. Between 500 and 1,000 feet, call to engage the autopilot, and I'll engage the correct vertical, lateral, and speed modes. Note that your system is set up in a fully automatic mode once the autoflight is engaged. That is, the autothrottle will try to close on the RTA.

In addition to playing your role as pilot, please feel free to come out of character and discuss your thoughts on the interface or interaction at any time. That is, please use the scenario as a means to imagine this system in the real world, and also give us your expert opinion all along the way.

Do you have any questions?

Unpause simulator
After takeoff Check AP Modes Engaged: SPEED HDG SEL ALT HOLD

Detroit to Dulles ATC Sequence

Enter RTA Waypoint for the participant in the MCDU.

Citation 789H, cleared for takeoff, Runway 21L, fly runway heading, and climb maintain FL450.

Citation 789H, cleared direct Dryer.

Citation 789H, cross DRUZZ at __________ (set in between early and late)

Wait 1 minute

“Citation 789H, Dulles runway 19C temporarily closed for disabled vehicle. Expect runway 19L via RNAV GPS Y RWY 19L KIAD. If able, new RTA at DRUZZ is __________ (an earlier but still doable RTA) for direct routing to CRVER.”

Now assume that you had to advise ATC that you were unable to accept the RTA.

“Roger, Citation 789H. New RTA at DRUZZ is now __________ (20 min later than latest ETA) for increased traffic to RWY 19L. Expect SHNON Two Arrival as published.”

End of Scenario, PREPARE NEXT SIM CONDITION, give Participant Workload Instrument.

Post Scenario Questions:

What decisions do you need to make when accepting or rejecting an RTA?

What kinds of decisions might you make regarding fuel consumption and cost index?

What sorts of display information would you like to make trades that could several variables? For instance, you might get a shorter route and an earlier arrival, but you’ll have to fly much faster to make a substantially earlier RTA, and there may be a fuel burn tradeoff to make. Perhaps despite an increase in fuel consumption to the RTA waypoint, overall consumption may be reduced because of the preferred routing available if the RTA can be met. What would you want to know to solve the problem?

What “what if” comparisons do you wish you had available to make these decisions?

How would you like the interaction with ATC to go when negotiating an RTA?

Phoenix to Miami

RECHECK COUNTERBALANCE SHEET
SET DISPLAY CONDITION
TBO KPHX-KMIA (MS FlightSim), Check POS INIT, Complete PERF INIT and T3-PHX-MIA (MCDU)

Flight Plan
KPHX.MAXXO1.CNX.Q20.JCT.J86.LEV.Q102.CYY.CYY6

Runway	KPHX RWY 7L
Departure	PXR.BAYTA.CHOPR.GILAA.ADYAN.DRYHT.MAXXO.CNX (MAXXO1 Departure)
Enroute	Q20.JCT.J86.LEV.Q102
Arrival	CYY.DEEDS.WORPP (CYPRESS6 Arrival, WORPP is IAF for Approach)
Expect App	RNAV RNP Y RWY 8R

Participant Instructions

This scenario begins with your aircraft, Citation 789H, on the ground awaiting takeoff at Phoenix Sky Harbor Airport, Runway 7L, with a destination of Miami, FL. You are presently cleared along a route through southern New Mexico toward Junction VOR, JCT, the RTA waypoint.

Show the flight plan in the appropriate interface (MCDU, GFP, or EFB) including the RTA waypoint, Junction VOR (JCT).

Major thunderstorms are around, and you've heard a few negotiations between ATC and other aircraft discussing changing RTAs and required departure times.

BE SURE TO SHOW THE RTD PAGE.

I will play the role of air traffic control. If at any time you would initiate a conversation with ATC, please do. For instance, if you find that you need an amended clearance because you are unable to make an RTA, please make that call as you would in the real world.

Note that your system is set up in a fully automatic mode once the autoflight is engaged. That is, the autothrottle will try to close on the RTA.

In addition to playing your role as pilot, please feel free to come out of character and discuss your thoughts on the interface or interaction at any time. So please use the scenario as a means to imagine this system in the real world, and also give us your expert opinion all along the way.

Check parking brake set. Unpause simulator.

Phoenix to Miami ATC Sequence

Enter RTA Waypoint for the participant in the MCDU.

Citation 789H, Cross Junction at _______ (make it doable, toward late time)

(response)

Citation 789H, Say required time of departure to make junction at _________ (the RTA)

(response)

Citation 789H, Albuquerque Center reports an area of thunderstorms Southwest of Junction moving North toward with your trajectory prior to Junction. Can you make junction at _________ (30 minutes prior to early)

(response, unable)

Citation 789H, roger, advise ready to copy.

Citation 789H, cleared via MAXXO1 Departure, Corona, Q20, Junction, then as filed.

(load T4-PHX-MIA for pilot, make JCT the RTA waypoint)

Citation 789H, say ETA at Junction.

Citation 789H, roger, cross Junction at ___________ (ETA plus 5 minutes).

Citation 789H, say Required Time of Departure.

Citation 789H, roger, Runway 7L, line up and wait.

(wait for departure time)

Citation 789H, Runway 7L, cleared for takeoff

End of Scenario, PREPARE NEXT SIM CONDITION, give Participant Workload Instrument.

What decisions do you need to make when accepting or rejecting an RTA?

What “what-if” comparisons do you wish you had available to make these decisions?

How would you like the interaction with ATC to go when negotiating an RTA?

After Last (9th) Run

MCDU Data Entry Question:

How would you feel about entering RTA data in the MCDU? Could it be improved?

GFP Data Entry Question

Click on RTA fix and select "cross" from menu.

What are your thoughts on using a cross dialog box to enter a RTA?

For instance, with a clearance like "Citation 789H, cross BRUSR at 1200z"

How could this be improved?

EFB Data Entry Question

What sort of data entry would you want to do on an EFB?

Deliver Post-Experiment Questionnaire

Appendix B: Questionnaire

TBO HEURISTIC EVALUATION: POST-EXPERIMENT QUESTIONNAIRE

Date: _____________

Subject #: ____

Age: ____

Total hours flying (approx.): __________

Current aircraft type(s) AND hours on type(s): ______________________________

____

____

Current crew position. Please select *ALL* responses that apply from the list below:

- ❑ Captain.
- ❑ First Officer.
- ❑ Check airman.
- ❑ Instructor.
- ❑ Other (please specify e.g., DER Test Pilot, chief pilot, technical/test pilot, certification pilot).

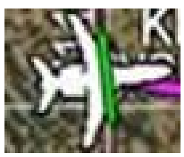
Current ratings/licenses. Please select *ALL* responses that apply from the list below.

- ❑ Private Pilot.
- ❑ Commercial.
- ❑ Instrument Rating.
- ❑ ATP.
- ❑ Instructor (e.g., CFI).

We are interested in your impressions regarding the design of the interfaces that you used today. In particular, we are interested in any problems that you experienced when using the interfaces so that we can then work to correct or improve them in later iterations of their design.

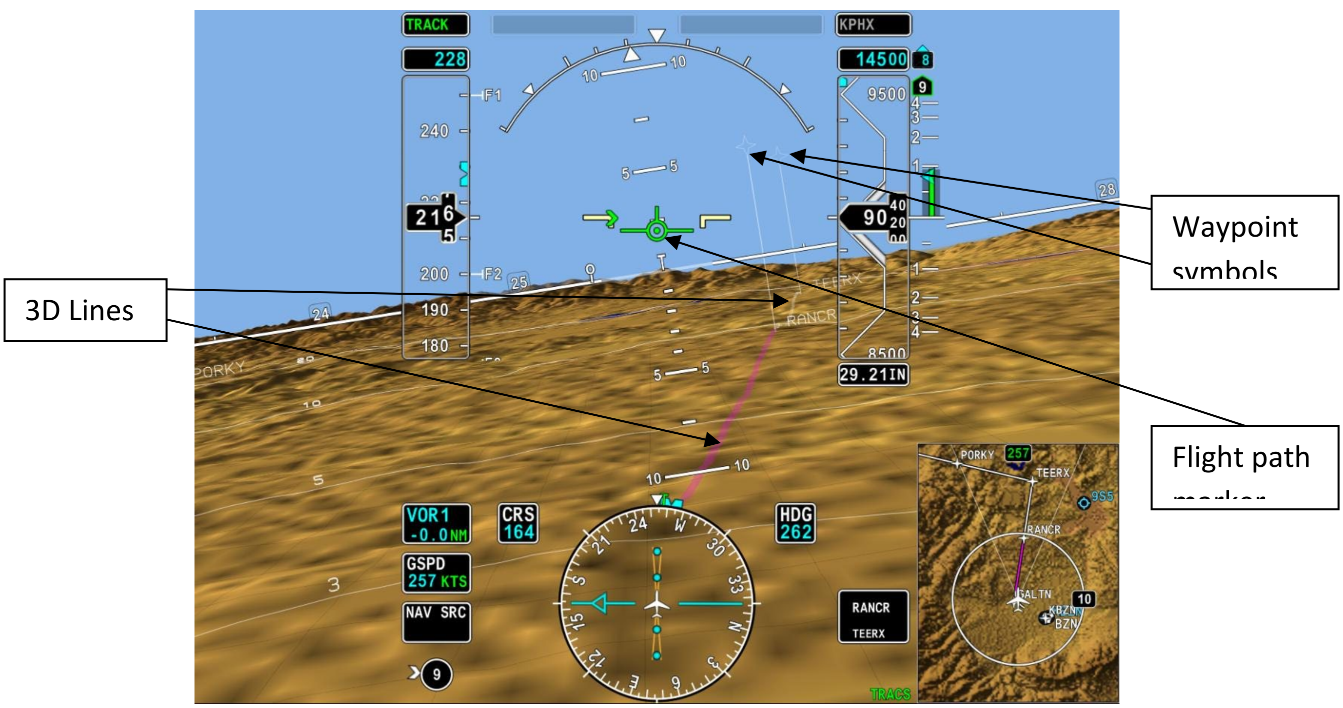
GRAPHICAL FLIGHT PLANNING DISPLAY

1. The following items pertain to the **graphical flight planning** display. Please provide your ratings about the following items below, and include any comments you have regarding the items.

Item			Rating (1 = worst, 7 = best)							Comments (e.g., Icon Color, Size of Graphic)
			1	2	3	4	5	6	7	
"On Time" RTA		**Symbol /Graphic**								
"Early" RTA		**Symbol /Graphic**								
"Late" RTA		**Symbol /Graphic**								
RTA Data Tag		**Symbol /Graphic**								

Item			Rating (1 = worst, 7 = best)							Comments (e.g., Icon Color, Size of Graphic)
			1	2	3	4	5	6	7	
Item			**Rating** (1 = worst, 7 = best)							**Comments** (e.g., Icon Color, Size of Graphic)
			1	2	3	4	5	6	7	
RTA Waypoint		**Symbol /Graphic**								
Controllable Map Scale **Range**		**Symbol /Graphic**								
Controllable Map Scale **Time**		**Symbol /Graphic**								

– The following questions pertain to the **integrated primary flight display**. Please provide your ratings about the following items below (see specific item locations below), and include any comments you have regarding the items.



Item	Rating (1 = worst, 7 = best)							Comments (e.g., Icon Colors, Size)
	1	2	3	4	5	6	7	

Item	Rating (1 = worst, 7 = best)							Comments (e.g., Icon Colors, Size)
	1	2	3	4	5	6	7	
3D Lines								
Flight Path Marker								
Waypoint Symbols								

– Please rate the following items in the **graphical flight planning** display below:

Item	Rating (1 = worst, 7 = best)	Comments (e.g., Icon Colors, Size)
	1 2 3 4 5 6 7	

Item	Rating (1 = worst, 7 = best)							Comments (e.g., Icon Colors, Size)
	1	2	3	4	5	6	7	
General design of the **Vertical Situation Display** (at bottom of image above)								
RTA in waypoint list 								

– Would the text “early” and “late” displayed next to the RTA numerals in the FPLN be preferable to the +/-?

–

❑ Yes
❑ No

Please explain your answer:

– Please list any suggestions that you have for improving the Vertical Situation Display:

For the next several questions, please **circle** the number that most closely matches your level of agreement with the statement. Please provide comments below each statement.

2. Please rate the **Vertical Situation Display (VSD)**, and include any comments you have regarding the display.

Worst						Best
1	2	3	4	5	6	7

Comments

– The graphical flight plan display supports good pilot decision making.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The graphical flight plan display is easy to learn.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The graphical flight plan display is uncluttered.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

- The graphical flight plan display requires excessive head-down time.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

- There are aspects of the graphical flight plan display design that make the crew vulnerable to error.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

3. The graphical flight plan display kept me informed about what was happening.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

4. The graphical flight plan display functional behavior was clear (what the system is doing and why).

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The graphical flight planner has all the functions and capabilities I expect it to have.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The graphical flight planner will support me in meeting an RTA.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– I would enjoy having this graphical flight planner system.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

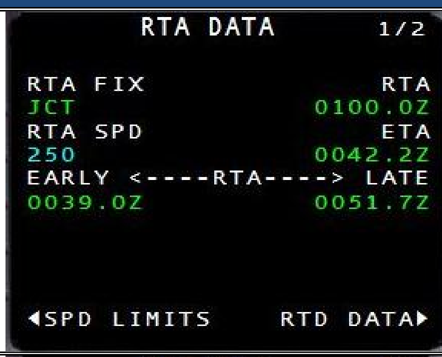
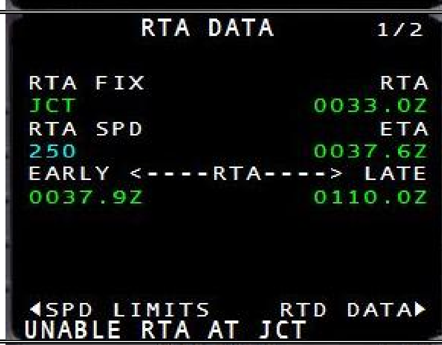
–

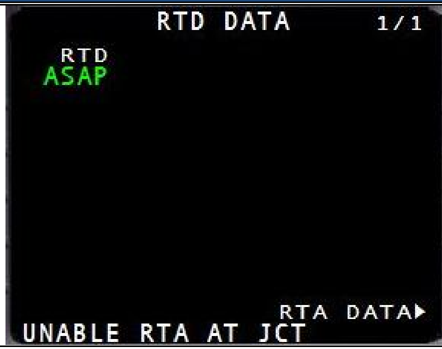
– What were your <u>three favorite features</u> of the graphical flight planner (please use the back of the page if necessary)?

– What were your <u>three *least* favorite features</u> of the graphical flight planner (please use the back of the page if necessary)?

MULTI-FUNCTION CONTROL DISPLAY UNIT (MCDU)

1. The following items pertain to the **MCDU RTA Pages**. Please provide your ratings about the pages, and include any comments you have regarding them.

Item		Rating (1 = worst, 7 = best)							Comments
		1	2	3	4	5	6	7	
MCDU Can Make RTA									
MCDU Unable to Make RTA									
MCDU Can Make RTA RTD									

Item		Rating (1 = worst, 7 = best)							Comments
MCDU Unable to Make RTA RTD ASAP		1	2	3	4	5	6	7	

– What improvements would you make to the MCDU RTA pages (please use the back of the page if needed)?

For the next several questions, please **circle** the number that most closely matches your level of agreement with the statement. Please provide comments below each statement.

– The MCDU RTA function supports good pilot decision making.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments

– The MCDU RTA function is <u>easy to learn</u>.

Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7

Comments:

– The MCDU display of RTA functions is <u>uncluttered</u>.

Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7

Comments:

– The MCDU RTA function requires <u>excessive head-down time</u>.

Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7

Comments:

– There are aspects of the MCDU RTA function that <u>make the crew vulnerable to error</u>.

Strongly Disagree 1	2	3	4	5	6	Strongly Agree 7

Comments:

2. The MCDU RTA function <u>kept me informed about what was happening</u>:

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

Comments:

3. The MCDU RTA <u>functional behavior was clear</u> (what the system is doing and why):

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

Comments:

- The MCDU RTA function <u>has all the functions and capabilities</u> I expect it to have:

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

Comments:

- The MCDU RTA function will support me in meeting an RTA":

Strongly Disagree 1 2 3 4 5 6 7 Strongly Agree

Comments:

– I would enjoy having this MCDU RTA function:

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

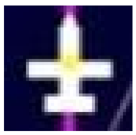
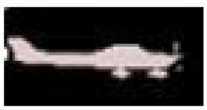
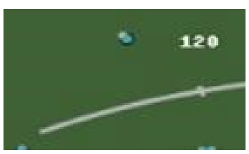
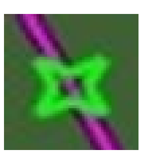
Comments:

– What were your three favorite features of the MCDU RTA function?

– What were your three *least* favorite features of the MCDU RTA function?

ELECTRONIC FLIGHT BAG (EFB)

1. The following questions pertain to the **EFB**. Please provide your ratings about the following items below, and include any comments you have regarding them.

Item			Rating (1 = worst, 7 = best)							Comments (e.g., Icon Color, Size of Graphic)
			1	2	3	4	5	6	7	
Aircraft Symbol – Lateral Display		**Symbol /Graphic**								
Aircraft Symbol – Vertical Display		**Symbol /Graphic**								
Compass		**Symbol /Graphic**								
Trajectory Line		**Symbol /Graphic**								
Waypoint - Next		**Symbol /Graphic**								
Waypoint – Beyond Next		**Symbol /Graphic**								

- The following questions pertain to the EFB's **Lateral and Vertical display functions**. Please provide your ratings about the items, and include any comments you have regarding them.

- Please rate the acceptability of the **zoom** function on the lateral display and vertical display (i.e., using two fingers in a pinching gesture to magnify, or a "pulling apart" gesture to de-magnify):

Completely Unacceptable						Completely Acceptable
1	2	3	4	5	6	7

Comments:

- Please rate the acceptability of placing a finger on a waypoint symbol to select and obtain information about a waypoint:

Completely Unacceptable						Completely Acceptable
1	2	3	4	5	6	7

Comments:

- Please rate the **overall** acceptability of the time slider, which provides future information on both the Lateral and Vertical displays (NOTE: questions about "free scroll" and "scroll by minute" capabilities are below – please only rate your impression of overall acceptability):

Completely Unacceptable						Completely Acceptable
1	2	3	4	5	6	7

Comments:

– Please rate the <u>acceptability of the “free scroll” function of the time slider</u> (i.e., dragging a finger along the scroll bar to control the Represented Time value):

Completely Unacceptable 1	2	3	4	5	6	Completely Acceptable 7

Comments:

– Please rate the <u>acceptability of the “scroll by minute” function of the time slider</u> (i.e., placing a finger on the arrow symbols at the far left and right of the scroll bar to advance the Represented Time value by +/- one minute):

Completely Unacceptable 1	2	3	4	5	6	Completely Acceptable 7

Comments:

– The following items and questions pertain to the EFB’s **bottom display panes**. Please provide your ratings about the items and include any comments you have regarding them, or answer the questions.

Item			Acceptable	Unacceptab	Comments/Answer
Waypoint List		**Text**			
		Color			
		Size			
	What does the yellow text signify?				

Item			Acceptable	Unacceptab	Comments/Answer
	What does the <u>magenta text</u> signify?				
	What does the <u>white arrow</u> next to the magenta text signify?				
	What does the <u>green text</u> signify?				
Information Window		**Text**			
		Color			
		Size			
	What is the relationship between the “ETA” value and the “Time” value?				

Item			Acceptable	Unacceptab	Comments/Answer
Layer Controller		**Text**			
		Color			
		Size			

– The following questions pertain to the **bottom display pane functions** of the EFB. Please provide your ratings about the items, and include any comments you have regarding them.

– Please rate the acceptability of placing a finger on the arrow symbols on the Waypoint List scroll bar to view additional waypoints on the trajectory:

Strongly Dislike						Strongly Like
1	2	3	4	5	6	7

Comments:

- Please rate the acceptability of placing a finger on the labels of the Layer Controller to toggle the visibility of the various layers of the lateral and vertical displays:

Strongly Dislike						Strongly Like
1	2	3	4	5	6	7

Comments:

- What improvements would you make to the EFB?

For the next several questions, please **circle** the number that most closely matches your level of agreement with the statement. Please provide comments below each statement.

– The EFB supports good pilot decision making.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments

– The EFB is <u>easy to learn</u>.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The EFB is <u>uncluttered</u>.

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

–

–

–

– The EFB requires excessive head-down time.

Strongly Strongly

Disagree Agree

1	2	3	4	5	6	7

Comments:

- There are aspects of the EFB that make the crew vulnerable to error.

Strongly Disagree | Strongly Agree

1	2	3	4	5	6	7

Comments:

2. The EFB kept me informed about what was happening:

Strongly Disagree | Strongly Agree

1	2	3	4	5	6	7

Comments:

3. The EFB's functional behavior was clear (what the system is doing and why):

Strongly Disagree | Strongly Agree

1	2	3	4	5	6	7

Comments:

- The EFB has all the functions and capabilities I expect it to have:

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– The EFB will support me in meeting an RTA:

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

Comments:

– I would enjoy having this EFB":

Strongly Disagree						Strongly Agree
1	2	3	4	5	6	7

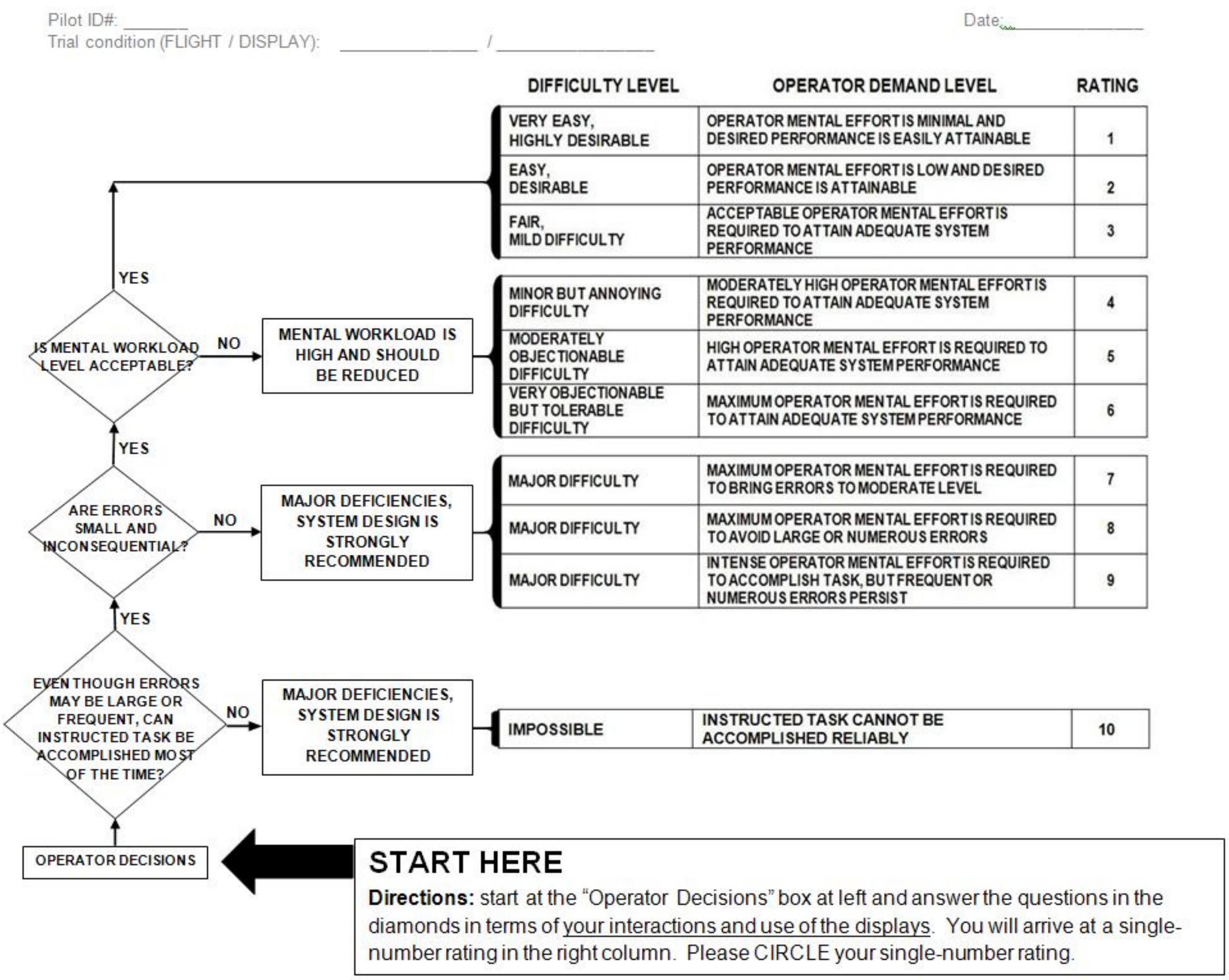
Comments:

–

- What were your <u>three favorite features</u> of the EFB (please use the back of the page if necessary)?

- What were your <u>three *least* favorite features</u> of the EFB (please use the back of the page if necessary)?

Appendix C: Modified Cooper-Harper Workload Rating Scale



Appendix D: Counterbalance Order

Subject	Trial Order 1	2	3	4	5	6	7	8	9
1	PHX-MIA GFP ☐	PHX-MIA MCDU ☐	PHX-MIA EFB ☐	BZN-PHX MCDU ☐	BZN-PHX GFP ☐	BZN-PHX EFB ☐	DTW-IAD MCDU ☐	DTW-IAD EFB ☐	DTW-IAD GFP ☐
2	BZN-PHX EFB ☐	BZN-PHX MCDU ☐	BZN-PHX GFP ☐	DTW-IAD MCDU ☐	DTW-IAD GFP ☐	DTW-IAD EFB ☐	PHX-MIA GFP ☐	PHX-MIA MCDU ☐	PHX-MIA EFB ☐
3	DTW-IAD MCDU ☐	DTW-IAD GFP ☐	DTW-IAD EFB ☐	BZN-PHX GFP ☐	BZN-PHX MCDU ☐	BZN-PHX EFB ☐	PHX-MIA MCDU ☐	PHX-MIA EFB ☐	PHX-MIA GFP ☐
4	PHX-MIA GFP ☐	PHX-MIA EFB ☐	PHX-MIA MCDU ☐	DTW-IAD EFB ☐	DTW-IAD GFP ☐	DTW-IAD MCDU ☐	BZN-PHX GFP ☐	BZN-PHX MCDU ☐	BZN-PHX EFB ☐
5	BZN-PHX EFB ☐	BZN-PHX GFP ☐	BZN-PHX MCDU ☐	PHX-MIA GFP ☐	PHX-MIA MCDU ☐	PHX-MIA EFB ☐	DTW-IAD GFP ☐	DTW-IAD EFB ☐	DTW-IAD MCDU ☐
6	DTW-IAD MCDU ☐	DTW-IAD EFB ☐	DTW-IAD GFP ☐	PHX-MIA EFB ☐	PHX-MIA MCDU ☐	PHX-MIA GFP ☐	BZN-PHX EFB ☐	BZN-PHX MCDU ☐	BZN-PHX GFP ☐