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# Human Factors Considerations for Performance-Based Navigation

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**December 2006**

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## Executive Summary

A transition toward a performance-based navigation system is currently underway in both the United States and around the world. Performance-based navigation incorporates the use of Area Navigation (RNAV) equipment that is not reliant on the location of ground-based navigation aids. In addition to the point-to-point capabilities offered by RNAV, new procedures are also being implemented that incorporate Required Navigation Performance (RNP). Aircraft certified for RNP operations are able to meet specific requirements for position determination and track conformance. RNAV and RNP procedures offer significant benefits to both operators and air traffic managers. These benefits include better access to terrain-limited airports, more environmentally friendly flight paths, and significant gains in airspace efficiency. Performance-based operations are being implemented in both the terminal area and en route environments.

The implementation of these procedures has produced tangible benefits at a number of different airports. According to the FAA Roadmap for Performance-Based Navigation, new RNAV procedures in the terminal area have reduced air-ground communications and led to reductions in flight times and distances.[2] These positive outcomes notwithstanding, the transition to RNAV and RNP, has caused some human performance issues to emerge that have prevented the full realization of benefits from the new procedures. As new performance-based applications are considered, other human performance issues are also anticipated. To provide a more seamless transition to RNAV and RNP, a National Aeronautics and Space Administration (NASA) and Federal Aviation Administration (FAA) project has been initiated to identify a broad set of human factors issues associated with performance-based navigation and to make recommendations for prioritizing work on those issues.

The primary objective of the project is to provide greater awareness of human-performance issues related to RNAV and RNP to a wide range of stakeholders. Products from this project are expected to benefit air navigation service providers, regulators, manufacturers, and training professionals. With this awareness, it is expected that instrument procedures, training programs, regulatory reviews, and operational procedures will place additional emphasis on human factors.

To address these goals, the project has developed and prioritized a list of human factors issues related to performance-based navigation. The list concentrates on air carrier operations. It was created based on a literature review, attendance at government/industry committee meetings, and discussions with technical experts. Major results from a separate review of Aviation Safety Reporting System (ASRS) data related to RNAV Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs) have also been incorporated.[6] Where possible, the list has been supplemented with summary information on known efforts to address these issues. Categories considered include operational procedures, aircraft equipment capabilities, procedure design, charting, and the application of current approach categories and flight plan suffixes in a performance-based environment. While these issues are grouped and discussed separately, many of them are interdependent or have multiple implications. They may also combine and cause a cumulative effect on operations.

Air traffic control procedures have been affected by the transition to performance-based navigation. Some conventional terminology is less able to accommodate the greater prevalence of route-based clearances associated with RNAV procedures. Although often necessary for air traffic management purposes, late runway changes assigned by controllers can increase pilot workload due to necessary programming changes within the Flight Management System (FMS). Pilots also require greater awareness of this procedure management issue and are encouraged to take extra care to ensure that the correct runway is loaded into the FMS after a change has occurred.

RNAV and RNP procedures have increased the importance of some tasks performed by pilots and have also introduced some new ones. Pilots must allow adequate time to properly load and brief their SID, STAR, and approach charts. While containing many elements common with existing procedures, these procedures can be more detailed than their conventional counterparts. Considering the increased reliance on the FMS for RNAV and RNP procedures, airlines may benefit from reviewing their training programs and ensuring that they meet pilot workload and situation awareness demands.

RNAV and RNP procedures require tight adherence to the published path and are often more sensitive to variance in path construction and guidance techniques amongst flight management systems. Differences such as path construction at waypoints, handling of speed constraints, and mode transitions can cause path inconsistencies. In some cases, these differences have resulted in traffic conflicts. In addition to the FMS, design considerations related to other supporting systems were also noted.

The FMS navigation database plays a key role in the implementation of performance-based procedures. Several technical experts have recommended more thorough database integrity checking at all data processing levels, from origination by source countries to procedure coding in a particular FMS unit.

Over-complexity has been cited as a common concern for several different types of terminal area procedures. Several aspects may contribute to complexity including the number of waypoints required for RNAV procedures, chart clutter, successive altitude constraints in close proximity, and conditional constraints. Commonality with other procedures has also led to misidentification by pilots. A set of guidelines that assesses the operational effects of procedure design attributes (both individually and in combination) could be valuable for enabling the design of new procedures that achieve benefits while maximizing human performance.

RNP approaches now provide the capability to incorporate highly precise turn segments. This significant enhancement is causing airline personnel to re-think traditional definitions of "stabilized" approaches. The appropriate minimum altitude for turn segments and the use of turn segments at decision altitude are also major issues requiring further consideration.

Many have cited the current approach naming and approach classification system as inadequate to support performance-based navigation. This system includes approach naming conventions based on aircraft equipment and the distinction between "precision" and "non-precision" approaches. A new classification system could improve clarity, but would need to consider the broad impact of the current system.

Single letter flight plan suffixes used to delineate various equipment capabilities to controllers have also been called into question. In a performance-based environment, these codes may be insufficient for controllers to determine whether an aircraft is capable of performing a particular procedure.

Issues were prioritized based on recommended criteria from the Performance-based Aviation Rulemaking Committee (PARC) Human Factors Working Group, their potential impact on performance-based navigation, their prevalence in discussion at committee meetings, and the importance assigned to them by technical experts. Major issues that are recommended for near-term focused consideration include the

- development of human factors guidelines for instrument procedures,
- application of lessons learned from prior experience with specially-tailored RNP approaches toward implementation of public RNP approaches,
- continuation of efforts to resolve operational issues associated with RNAV SID and STAR procedures,
- review of approach naming and approach classification systems, flight plan suffixes, and assessment of proposed new systems designed to better accommodate performance-based operations,
- resolution of major issues related to chart/database commonality,
- review of aircraft equipment-related impact of RNAV and RNP operational events,
- and a review of several specific issues related to the use of barometric vertical navigation ("Baro VNAV").

Decisions to consider targeted investigation of a particular issue should consider priorities, available resources, and the ongoing work of other organizations. Strong collaboration between different groups addressing these issues will enable more efficient use of resources and a greater likelihood that compatible solutions will be realized.

# Introduction

## Motivation

In the U.S. National Airspace System and elsewhere in the world, a move is underway to transform navigation services from those emphasizing the use of specific sensors to those that focus on a performance capability. As part of this trend, more and more aircraft are being flown using *area navigation* (RNAV), a technology that allows point-to-point travel without regard to the location of ground-based radio stations. An extension of RNAV capability, known as Required Navigation Performance (RNP), specifies various levels of performance capabilities. Aircraft certified to a particular RNP have a demonstrated ability to remain within a containment area defined by their capability level.[1]

RNAV and RNP are seen as key enabling factors in improving the efficiency and capacity of the National Airspace System (NAS).[2] New procedures that rely on RNAV capabilities provide pilot-navigated routes that conform to local air traffic flow management needs and meet terrain and airspace challenges. Lower path tracking variability associated with these procedures improves consistency and allows controllers to use available airspace more efficiently. Controllers are able to issue more route-oriented clearances and rely less on radar vectoring in the terminal area. This change has reduced air-ground communications and led to more organized and predictable traffic flows. Because RNAV routes are no longer constrained by the location of ground-based navigation aids, procedures can also be developed that improve access while avoiding unusable airspace. RNAV provides additional options for procedure designers to accommodate challenging constraints such as terrain, noise-sensitive areas, and special use airspace.[3] These benefits relate directly to the performance-based services and trajectory-based operations capabilities envisioned for the Next Generation Air Transportation System (NGATS).[4] The Joint Planning and Development Office (JPDO), a consortium of government agencies and industry representatives, has been chartered to implement the NGATS by 2025.

RNAV and RNP are already yielding significant benefits. At the same time, these capabilities have led to some fundamental changes in aircraft operations, flight crew and controller procedures, and in supporting aircraft and ground-based automation systems. As expected with any transition, some human performance issues have emerged during operations.

Issues have been identified in several areas, including air traffic control (ATC) communication, the ability to perform RNAV procedures with various legacy systems, procedure design and charting, and the use of existing procedure classification systems employed by the Federal Aviation Administration (FAA).

Many of these issues are not unique to RNAV and RNP operations. The new emphasis on trajectory-based operations has highlighted vulnerabilities that existed with legacy procedures and equipment but were not frequently exercised. In many cases, the new procedures have increased opportunities to use existing equipment and communication conventions. Pilots and controllers are also adapting to a more precise system that requires even greater attention to good operating procedures.

Human performance issues are being discussed in various forums. A number of government/industry committees such as the RNAV Task Force, the Performance-Based Aviation Rulemaking Committee (PARC), and several International Civil Aviation Organization (ICAO) panels regularly discuss these issues and potential mitigation strategies. Web-based information sites such as Bluecoat allow airline pilots to discuss issues they've encountered with others in the community. Issues are also raised through the Aviation Safety Reporting System (ASRS), a searchable database sponsored by the FAA and administered by the National Aeronautics and Space Administration (NASA). FAA documents are being developed to address them. With discussions taking place in multiple venues and across a number of organizations, there appears to be a strong need to organize the issues raised, discuss their relative importance, and make the information available to a wider audience.

## Development of Issues List and Intended Purpose

In response to these needs, the NASA Langley Research Center, under joint sponsorship from the FAA, has undertaken a project to assemble and prioritize a list of human factors issues related to performance-based navigation. These issues focus on air carrier operations. The purpose of the Issues List and supporting analysis is to improve awareness of human factors for NAS stakeholders who conduct RNAV and RNP operations or offer related products and services. It also serves to provide guidance for government/industry committees that address RNAV and RNP issues. The document could be used effectively in a number of different ways. Air navigation service providers and manufacturers could take the issues raised into account when designing instrument procedures and aircraft systems, respectively. FAA personnel may develop or revise advisory circular material and certification guidelines for aircraft and flight crews involved in RNAV and RNP operations. Committees and research organizations could also consider the prioritized list when allocating resources to study relevant issues. The document may be helpful for training professionals who develop RNAV and RNP-related course material.

This document focuses primarily on human performance issues that have occurred during implementation of RNAV and RNP. It is not intended to be a harsh critique of these operations, nor to imply that the procedures are unsafe or inherently difficult. Comparable or potentially more significant issues could exist with legacy procedures and are not addressed specifically in this document. A strong consensus exists in the aviation community that RNAV and RNP provide major safety, air traffic efficiency, and economic advantages over legacy systems and procedures. The reader is encouraged to consider the issues presented in light of these significant benefits. Coordinated actions taken to address these issues will likely lead to even greater operational performance.

The Issues List has been developed through a wide literature review, attendance at government/industry committee meetings, and discussions with technical experts. As part of this effort, the authors conducted a more detailed review of the ASRS database for events occurring during the operation of RNAV Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs). While the details of the ASRS review have been discussed in a separate report,[6] the high level findings have been incorporated into the Issues List.

Appendix A presents the list of issues compiled during this study. The first several columns identify the source of the issue. Many of the issues were captured from presentations given at committee meetings. Others were uncovered during a literature search of FAA publications such as Issue Papers, Advisory Circulars, Orders, and bulletins; a review of airline information websites such as Bluecoat, an assessment of pilot deviation reports and ASRS records, and through technical discussions with expert users. Where available, the expert identifying the issue and his or her organization are provided.

A category is assigned for each issue. While many issues have ties to several different functional areas, category assignment is based on the aspect deemed to be most directly related to the issue cause. List categories were organized to capture human performance issues related to procedures, aircraft equipment, and information exchange. The left column of Table 1 provides a list of all categories considered.

Many issues have a cause/effect relationship and therefore impact other areas. Some of them also have roots in more than one categorical area. In these cases, additional keywords are provided. Keywords may include the category labels or may come from an additional set of next level descriptors. The right column of Table 1 provides additional keywords. Some keywords are considered to be sub-categories and are listed under their corresponding higher level attribute. If an issue affects a specific keyword, the list references the keyword. However, if it affects several sub-categories under the same higher level category, the category may be listed in one of the keyword columns. Up to two keywords are provided for each issue.

Table 1 Categories and Keywords Used in Issues List

| Category | Keywords/Sub-Categories |
|---|---|
| ATC Procedures | |
| Flight Crew Procedures | |
| Airline Procedures | Pre-Departure Clearance (PDC) |
| | Training |
| Equipment Capabilities | FMS (other than navigation database), |
| | Electronic Flight Instrumentation System (EFIS) |
| | Alerting |
| | Autopilot |
| | Distance Measuring Equipment (DME)/DME |
| | Inertial |
| | Electronic Flight Bag (EFB) |
| FMS Navigation Database | |
| Procedure Design | RNAV SID/STAR |
| | RNAV Approaches |
| | RNP Approaches |
| | RNP Parallel Approach Transition (RPAT) |
| | Q Routes |
| | FMS Offsets |
| Charting | |
| Chart/Database Commonality | |
| Approach Naming and Approach Classification | |
| Flight Plan Suffix | |
| NOTAMs | |
| Collaboration | |

Category organization within Table 1 is not necessarily based on order of importance, but has been chosen to facilitate description in later sections. Procedures can largely be broken down into those pertaining to pilots, air traffic controllers, and airlines. Pilot training and pre-departure clearance (PDC) formats are considered part of airline procedures. Equipment capabilities were often found to contribute to human performance issues. These instances included cases where pilots needed to accommodate the functional limitations of aircraft systems. Design issues have also been included. Due to the large number of entries pertaining to FMS navigation databases, these records are separated from other FMS functions such as guidance, flight planning, and aircraft performance. Procedure design is broken down into various en route and terminal procedures currently in use or proposed. Many issues were found that linked FMS navigation databases with the charts they supported. These issues are included as part of a separate category (Chart/Database Commonality). Approach Naming and Approach Classification includes both the distinction between precision and non-precision approaches as well as the approach naming convention. The latter is currently based on the type of equipment used to fly the approach, but may eventually incorporate a performance-based definition. Flight plan suffixes refer to the single letter codes used to identify relevant equipment capabilities onboard a particular aircraft. Notices to Airmen (NOTAMs) issues were captured that pertained specifically to RNAV and RNP systems and operations. Finally, several issues were documented concerning collaboration between various organizations making decisions on human factors for performance-based navigation.

Appendix A provides a priority assessment of each issue (high, medium, or low). Priorities were assigned based on expert review, time criticality, and potential for broad-reaching impact. Additional details of the prioritization scheme are provided in a later section.

The synopsis includes a summary description from the perspective of the person or entity raising the issue. It may not include other perspectives of the same issue, although those viewpoints may be captured as additional issues. Where possible, information is provided on known ongoing or previously occurring activities taken to address the issue. Due to the dynamic nature of this material and the large number of ongoing efforts, it is likely that some relevant activities have not been captured. Even when activities have taken place that are expected to provide complete resolution, the issues are still recorded in order to document lessons learned. These lessons may benefit stakeholders facing similar situations in the future and may also be helpful to other organizations (either domestic or international) at different stages of RNAV and RNP implementation.

## Issues List Findings

Issue descriptions below are described in the order listed in Table 1 and do not necessarily reflect order of importance.

### ATC Procedures

The introduction of RNAV and RNP procedures has led to opportunities for more route-oriented climb and descent clearances to be issued by ATC. A key advantage of RNAV SID and STAR procedures has been a reduction in vector and speed-based commands in the terminal area. These changes have improved efficiency and have generally reduced controller workload; however, they have also revealed several shortcomings in existing ATC terminology.

One particular area that has caused pilot confusion relates to the distinction between a clearance to climb or descend uninhibited with one that requires compliance with intermediate altitude constraints. When the controller expects compliance with published constraints, the term, “descend via” is often used. There is no corresponding term for a climb scenario. Industry groups and controller personnel are currently working to address this gap through development of a “climb via” phraseology and procedure. Human factors validation testing is underway and training material is being developed in support of this procedure. Changes to the Controllers’ Handbook, 7110.65R[7] and the Aeronautical Information Manual (AIM),[8] provide more specific guidance as it relates to “descend via” and runway transitions. These changes were motivated by the Pilot/Controllers Procedures & Phraseology Action Team under the PARC. The team is made up of FAA and industry subject experts.

Pilots have noted instances in ASRS records where they were confused by the controller’s altitude assignment while they were operating off the published portion of an arrival or departure procedure. Controllers should provide an altitude assignment while an aircraft is being vectored and state explicitly whether a flight crew should resume compliance with charted restrictions after re-joining the route. Changes to the Air Traffic Control Order[7] and AIM[8] provide additional clarification on altitude assignments for cases where aircraft are cleared to proceed direct to a fix contained in a STAR procedure and then to “descend via” the arrival. These issues are also relevant for conventional SID and STAR procedures.

In response to changing air traffic needs, it sometimes becomes necessary for controllers to change the assigned runway for a departing or arriving aircraft. This change often requires the flight crew to perform several steps to re-program the aircraft’s FMS. Necessary changes include selecting a new runway, choosing a new runway transition, and clearing any resulting route discontinuities. Correct programming is even more important in an environment such as RNAV and RNP that emphasizes trajectory-based aircraft control close to the runway end. When multiple-runway operations are in effect, an aircraft's flight path could conflict with other traffic if the route is improperly programmed. Re-programming errors in operational service have led to path deviation errors and traffic conflicts. Performing the required changes can greatly increase crew workload, especially when at lower altitude or closer to the runway. Time pressures associated with immediate takeoff clearances can also be problematic when flight crews bypass essential FMS reprogramming verification. Focused training may be beneficial for both pilots and controllers. This training could emphasize proper and methodical re-programming by pilots and awareness by controllers to exercise caution when making changes during critical flight regimes.

Considering the programming changes that a crew must perform after a runway change, there is active discussion on ways that departing flights can be given information related to their runway assignment prior to push-back. The use of either Air Terminal Information Service (ATIS) or PDC has been discussed, but some have expressed concerns that these sources may cause confusion related to the clearance status of the information.

Another ATC change that can affect pilot performance occurs when a controller must change the altitude or speed assignment from that published on the chart. This revision often requires the aircraft to leave the FMS Vertical Navigation (VNAV) path and may make it more difficult to meet downstream waypoint altitude or speed restrictions. Controller training now emphasizes that pilots should be kept on the published procedure when possible.

ATC roles have also been discussed related to two en route RNAV procedures: "Q" routes and FMS offsets. Q routes are high altitude RNAV airways and FMS offsets allow pilots to fly their FMS paths at a specified offset left or right of course. A possibility exists that controllers may be asked to monitor the status of critical Distance Measuring Equipment (DME) stations for Q routes. Lost communication procedures are under discussion for FMS offsets. Any additional procedures for controllers should be considered in context of their existing duties.

## Flight Crew Procedures

Flight crew procedures have also been substantially affected by the transition toward performance-based navigation. With generally more detailed procedures, controller expectations of repeatable and predictable flight paths, and requirements for additional programming, flight crews must remain even more vigilant.

Hand flying RNAV SIDs and STARs that contain multiple vertical constraints has likely contributed to altitude deviations. Autopilot use for multi-segmented procedures is recommended or required by several airlines. In addition to the use of autopilot, the choice of autoflight mode also contributes to the pilot's ability to fly a precise path and meet restrictions. Establishment of a consistent engagement altitude for the Lateral Navigation (LNAV) mode has been recommended in order to improve path predictability.

Prior to conducting an RNAV or RNP procedure, pilots must verify that their equipment meets the proper requirements. For RNP procedures, they must be cognizant of the RNP requirement for each approach segment and must also monitor the aircraft's Estimate of Position Uncertainty (EPU).[1] EPU relates to the ability of the aircraft's position sensors to meet the accuracy requirements for a particular RNP level. The total system error, defined as the vector sum of the path definition, path steering, and position estimation errors, must be within the RNP value 95% of the time.[1] Current FMS equipment requires the pilot to enter the RNP value each time it changes for a new segment. These additional tasks have occasionally led to high crew workload. Near term additions to the navigation database will include RNP for enroute and approach segments. However, not all FMSs are capable of using the Navigation Database-provided RNP values. Regardless, the flight crew must ensure the charted RNP value is correctly entered into the FMS.

Crew procedures must be tailored for the specific RNAV equipment used. For example, an RNAV SID performed with an Inertial Reference Unit (IRU) or DME/DME requires that the FMS be properly aligned prior to takeoff. Some pilots flying older aircraft without runway position updating have neglected to perform this task. This omission could result in a map shift shortly after departure and these map shifts have contributed to lateral deviations. Procedural mitigations have helped address this issue.

## Airline Procedures

Airline company procedures can affect pilot operations in the performance-based NAS. The most direct applications of this relationship include airline training programs and the issuance of PDCs.

### *Pre-Departure Clearance (PDC)*

Proper understanding of the aircraft and crew's ability to fly particular RNAV and RNP procedures is important to ensuring that the resulting ATC clearance can be accepted by the flight crew. When the dispatch office files for a procedure that is unavailable to a particular aircraft type, potential errors can result when pilots obtain the clearance.

Problems may also ensue when the ATC clearance is different from the flight plan filed by the dispatch office. In several observed cases, the flight crews neglected to extract this important information when retrieving their clearance by PDC. In their ASRS reports, many pilots stated that the clearance change had been embedded in the footnotes or remarks section and had not drawn their attention. Pilots also cited preprogramming the FMS in anticipation of a preferred route or dispatch issued clearance and having not realized the PDC was different. In response to these concerns, some airlines have changed their PDC formats in order to highlight important changes. This issue is likely still a problem for airlines using older formats.

### *Training*

Pilot training is frequently challenged by full syllabi and limited available time. For these reasons, airlines have traditionally been unable to spend substantial time covering the intricacies of FMS operations. Pilots often learn basic operations in class, but require on-the-line experience to become comfortable with additional features. These features may vary across different aircraft (even within the same model). Problems on RNAV procedures can occur when a crew has only received limited FMS training or lacks recent experience. High workload situations can develop on complex procedures, especially when a change requires substantial re-programming of the FMS route. Additional emphasis on overall flight management/autoflight system modes and transitions (including those related to the FMS) may also be warranted. Multiple successive altitude crossing restrictions associated with RNAV SIDs and STARs have led to altitude deviations when pilots were caught off guard by unexpected mode changes. Many airlines have responded to these challenges by developing specialized FMS RNAV courses and requiring flight crews to demonstrate proficiency in regular simulator sessions.

## Equipment Capabilities

Equipment design features and limitations often impact pilot performance and workload in a performance-based environment. Discussion of these issues is intended to guide system designers when developing new products or enhancing current ones, as well as to make pilots aware of their aircraft capabilities when conducting RNAV and RNP procedures.

### *FMS (Other than Navigation Database)*

The FMS plays a key role in the implementation of performance-based navigation. Most FMS considerations related to RNAV and RNP operations primarily involve the navigation database. Nevertheless, the flight planning, trajectory generation, and guidance functions also have important roles.

Pilots appear to have an easier time complying with speed and altitude waypoint constraints on RNAV and RNP terminal procedures when using the FMS VNAV capability. When engaged, the VNAV mode commands appropriate pitch changes to comply with these restrictions. Use of an autothrottle and autopilot in conjunction with VNAV enables pilots to monitor the aircraft's altitude and speed without actively controlling to these targets. Pilots appear more susceptible to high workload events when these capabilities are unavailable or unused.

When flying an instrument procedure with the FMS, pilots monitor their progress by keeping track of the active waypoint on the Legs/FPLN page or by referencing the Navigation (Moving Map) Display (if installed). RNAV and RNP procedures make more use of the fly-by and fly-over waypoint type distinctions than their conventional counterparts. Current FMS designs do not provide waypoint type information to the pilot. This information may enable better overall awareness during the procedure. Pilots should be aware of fly-by and fly-over waypoint designations on instrument charts and how they should be flown. As a general rule, fly-over waypoints are discouraged for most procedure design when repeatable and predictable flight tracks are required.

Different FMS designs may vary in how they construct a path for a common waypoint type. During the initial implementation of RNAV departure procedures at Dallas Ft. Worth airport (DFW), wide variation in turn anticipation at a waypoint caused some aircraft types to overshoot the intended containment area. These path disparities occasionally led to traffic conflicts. Another potential difference is the way in which a FMS rejoins the outbound path after completing a large course change at a fly-over waypoint. These differences can contribute to air traffic separation issues when the resulting flight track differs from the controller's expectation. Procedure designers and controllers will likely benefit from increased awareness of differences in tracking performance that exist among flight management systems. This information should enable them to better accommodate areas where design differences are most likely to contribute to path variation.

Some flight management systems have design features that can cause unexpected behavior for pilots having less FMS proficiency or facing high workload situations. When a runway is selected on the FMS of Airbus aircraft, the FMS will automatically connect a programmed STAR with the runway using an approach transition ("Approach Via") if one exists. This action will delete any STAR waypoints subsequent to the one commencing the transition. Pilots must ensure the resulting route is consistent with that intended by ATC. On Boeing aircraft, the FMS Route Page does not necessarily show all waypoints along the route. Pilots should therefore use the Legs Page (rather than the Route Page) to ensure that all desired waypoints are part of the active flight plan. When clearing a route discontinuity, using the Legs page may prevent unintentional waypoint deletion. This discussion is not intended to pass judgment on the desirability of these features, but rather to highlight areas that may deserve specific mention during pilot training.

In other cases, concerns have been raised that some business and regional jets incorporate potentially challenging displays and interfaces. For example, the loaded runway may not be readily apparent on one regional jet's FMS Nav page. On this same aircraft, pilots have had trouble fully understanding FMS error messages. Designers of these systems may benefit from a study that assesses the operational impact of specific FMS attributes.

Tighter tolerances imposed by RNAV procedures sometimes challenge the capabilities of legacy systems. Two design features of a particular FMS have been mentioned with regard to their ability to manage waypoint speed constraints. These systems do not allow the pilot to enter a waypoint speed constraint without a crossing altitude. In addition, they disregard speed constraints after sequencing the corresponding waypoint. The former requires a pilot workaround, whereas the latter may affect aircraft tracking performance in a turn. It should be noted that these systems still provide highly reliable capability to conduct RNAV and RNP operations.

### *Electronic Flight Instrumentation Systems (EFIS)*

Sometimes the lack of a particular kind of equipment can affect flight operations as much as the characteristics of an available system. Pilots flying aircraft with pre-glass “steam gauges” are at a distinct disadvantage when flying RNAV and RNP procedures. The high speeds of commercial transport aircraft coupled with frequent turns and multiple altitude restrictions often make position situation awareness challenging.

Map displays that provide a situational representation of the aircraft’s position and corresponding navigation fixes allow pilots to anticipate course changes and monitor flight progress much easier than conventional course deviation instruments. Because of these issues, some airlines limit RNAV and RNP operations to those aircraft that have map displays associated with Electronic Flight Instrumentation Systems (EFIS). The importance of map displays may be even more pronounced for RNAV SIDs. On departure, the crew has less preparation time available to study the procedure and is often faced with even higher workload conditions than those occurring during RNAV STAR operations.

Display design issues are also emerging with the transition toward RNAV procedures. The additional flight segments contained in these procedures make it increasingly difficult for pilots to distinguish between the final approach and missed approach segments of an RNAV approach. In response to this issue, one aircraft manufacturer now specifies different colors to distinguish these approach segments.

### *Alerting*

RNP operations require alerting systems that indicate when the EPU has exceeded RNP. These alerts do not account for FTE and therefore do not notify the pilot that the aircraft position has exceeded the RNP value. On many aircraft, pilots monitor the aircraft’s position relative to RNP by referring to the FMS cross-track error on the Control Display Unit (CDU). Some have suggested this monitoring task would be easier if the cross-track error were displayed within the pilot’s primary field of view. This distinction may be even more important at low RNP levels. Boeing’s navigation performance scales are one potential design solution to this issue.

The navigation performance scales show the relationship between RNP, sensor performance (indicated as EPU, and available FTE). In addition to issuing containment advisories, they can be used to provide valuable trend information. Pilots have an immediate indication of degrading sensor performance when the additional position measurement uncertainty is shown to erode the margin available for FTE. The ability to which pilots are able to use this information may give valuable insight into the potential need for revised alerting system requirements.

General design attributes of RNP alerting systems are currently under discussion. Many of the design issues are common with other types of alerting systems, including visual and aural cues, color, intensity, flash vs. steady state, and location within the pilot’s scan. Human performance studies such as those previously conducted for traffic, windshear, and terrain warning systems may be beneficial in establishing design criteria.

### *Non-Satellite Position Sources*

Aircraft without Global Navigation Satellite System (GNSS) equipment (such as Global Positioning System (GPS)) normally use Distance Measuring Equipment (DME) receivers for position information. Onboard DME equipment receives signals from multiple ground-based navigation aids and combines those signals to determine position. Many of these aircraft are also equipped with inertial systems that determine position by integrating acceleration along multiple axes. These systems have unique operating characteristics that can cause position sensing errors if not properly monitored and initialized.

A DME station is considered “critical” if its loss prevents the aircraft from making a proper position determination. Status of critical DMEs must be properly monitored to ensure that adequate backup procedures are initiated. Development of these backup procedures has been identified as an issue for

RNAV SID/STARs and Q routes. Questions have been raised concerning whether pilots have adequate alerting mechanisms to indicate the loss of critical DME information. This issue will also be applicable to controllers if they are asked to monitor critical DMEs for Q routes as has been suggested. Controller workload issues may be important if they take on this additional task. Service volume saturation (high traffic density preventing proper reception) is an additional DME performance issue that should be considered for RNAV and RNP operations.

### *Electronic Flight Bag (EFB)*

Electronic Flight Bags are being introduced as a means to provide an electronic depiction of charted instrument procedures. Studies are ongoing to consider the effects of depicting detailed chart information in an electronic format. Issues have been raised including display layout, readability, and the ease in which a pilot can navigate through various menus to access the desired procedure. The proper positioning of an EFB is also important. Flight deck engineers will need to consider different implementation solutions for different aircraft.

## FMS Navigation Database

The FMS navigation database is likely the equipment component that has the most broad-reaching impact on performance-based navigation. Among other capabilities, the navigation database is used to store and allow pilot access to departure and arrival procedures, approaches, and waypoint locations. When selected and executed by the pilot, these waypoints or procedures become part of the aircraft's active flight plan.

An issue exists concerning the integrity of navigation information as it's transformed from paper to a standardized electronic format and then converted into a customized file for each airline. Various errors or general compatibility problems can occur in each stage during this process. These problems can then lead to unintended consequences when pilots use the FMS to access navigation information and fly the selected route.

Each country provides source navigation information to a database supplier that converts the data into electronic format. This source data may already contain errors when made available to the data supplier. Relocated navigation aids that were not properly updated in source data have led to map shifts. Potentially more serious consequences could be envisioned.

The data supplier converts the source data into a standardized ARINC 424 format.[9] Errors can be introduced through the arduous process of converting written data to an electronic format. ARINC 424 limitations add additional challenges to this process. Errors can also occur if the data supplier misinterprets the intent of the source data provider. In one case, a misinterpretation caused the data supplier to apply different coding to a missed approach segment from that intended, resulting in a completely new path that had not been previously checked for terrain clearance. In other cases, the source information may not be recorded in a format suitable for FMS processing. For instance, DME step-down fixes on an instrument approach are unnamed by the source. Consequently, these fixes must be assigned a name by the data supplier. This is one potential cause of a difference between charted and stored navigation data.

Errors can also be introduced when the ARINC 424 data is converted into a FMS-readable format and provided to the airline as a customized file. Various FMS features and limitations may require changes to the original ARINC representations. The resulting work-around can lead to undesirable effects in some cases. Some FMSs do not support particular leg types. To accommodate this trait, the FMS manufacturer may need to substitute another leg type in place of the one that's not supported. Other work-arounds may require the use of unconventional procedure naming. One FMS manufacturer that doesn't support STAR runway transitions resorted to creating different named procedures corresponding to each runway transition. This unconventional naming may be confusing to pilots and could result in improper route selection. Some charted trajectory change points involving multiple conditions are generally not supported by any FMS. Certain procedures require the pilot to initiate a turn when first reaching either a waypoint or an altitude. Other unsupported conditional waypoints include those where the altitude crossing restriction or procedure segment itself changes based on the landing runway.

Different coding techniques can cause significant variation in path construction and tracking. A recent study by Ottobre, O'Neill, and Herndon compared the effects of different FMS designs on path tracking performance.[10] They cite one example where a Los Angeles RNAV SID was coded three different ways. These differences caused controllers to observe flight paths that were less consistent and predictable than they had anticipated when the procedures were introduced. Despite these differences, track variability has reduced significantly as a result of RNAV SID and STAR implementation.

A process for FAA acceptance of navigation data quality standards at each step of this process with the exception of state-provided source data is now provided in Advisory Circular (AC) 20-153.[11] This guidance is expected to mitigate prior errors that occurred during the data transition process.

Additional anomalies related to the final navigation database accessed by flight crews have been reported. Fixes, altitude crossing restrictions, runway transitions, and even entire procedures have been reported missing. In other cases, waypoints were erroneously added to a procedure or an incorrect waypoint identifier was used. These errors can lead to route discontinuities or deviation from the intended flight path. Some fixes share a common identifier. Flight crews must be vigilant to ensure proper selection of the desired fix.

Navigation database errors may also influence an aircraft using VNAV on an approach. For both RNAV and conventional approaches, many flight management systems incorporate database information to generate a constant angle descent path to the Decision Altitude (DA). Although this VNAV path normally complies with all step-down altitudes, potential database or other FMS errors can lead to a constructed path that is below the charted step-downs. Additive FTE can further reduce obstacle clearances. When conducting VNAV approaches, pilots are required to use the barometric altimeter as the primary altitude reference source. In addition to tracking the path, they should monitor the aircraft altitude to ensure it remains above the step-downs.

The navigation database is an incredibly powerful tool, enabling flight crews to access virtually any navigation aid or procedure in the world. The FMS and its supporting database significantly reduce pilot workload by allowing them to append entire procedures onto existing flight plans. They also keep track of complex coding information for a vast number of departure, arrival, and approach procedures. Because of these capabilities, pilots have come to rely greatly on the navigation database access features and the coded data they store. These systems are highly reliable. Nonetheless, it's apparent that more work can be done to ensure the accuracy of source data and the proper representation of coded data in each FMS. Good suggestions have been raised in various forums. They include checks to verify accuracy of source data, combined with thorough validation procedures to ensure that each procedure can be correctly loaded and flown with predictable performance. More stringent criteria could be imposed for procedures in critical terrain or traffic environments. In addition to integrity checking, greater overall community awareness appears to be needed related to the consequences of different FMS designs on path tracking and flight crew performance. As RNAV and RNP procedures continue to propagate in the NAS, FMS design requirements may need to be revisited to ensure that necessary capabilities can be accommodated.

## Procedure Design

RNAV and RNP procedures span all segments of flight: departure, en route, arrival, and approach. Design of these procedures plays an important role in making sure that pilot and controller workload is manageable, human errors are kept to a minimum, and aircraft equipment enables pilots to fly the procedure as intended. These attributes are needed to achieve capacity goals while maintaining safety. This section describes design challenges and issues that have been raised for different types of RNAV and RNP procedures.

### *RNAV SID/STAR*

RNAV SID and STAR procedures offer airport planners greater flexibility to efficiently manage their airspace in the presence of constraints such as terrain, traffic from nearby airports, special use airspace, and noise restrictions. They also enable controllers to vertically separate arrivals and departures with fewer radio transmissions. Controllers are often able to clear an aircraft to comply with the charted profile instead of issuing successive level-off assignments. In order to accomplish these objectives, the procedures typically have more flight segments and waypoint constraints than their conventional counterparts.

While RNAV terminal procedures are not inherently difficult to fly, pilots appear to fly them more effectively when their aircraft equipment, operating procedures, and training emphasize situation awareness for trajectory-based flight paths. Several in-service issues have occurred when pilots encountered a distracting event while already compensating for equipment-related or procedural challenges. Considering the higher workload associated with flight in a terminal area, such distractions are somewhat typical. In this flight regime, pilots balance procedure monitoring tasks with checklist usage, automation transitions, and configuration changes among other things.

To maximize performance on RNAV SID and STAR procedures, it would likely be beneficial for designers to place additional emphasis on the operational impact of various procedure design attributes. Doing so would provide a greater margin for error when higher workload factors are present. Pilots and RNAV Task Force participants have identified high climb gradients, close waypoints, multiple speed and altitude restrictions in close succession, and unconventional at or below restrictions on climb-out as aspects that contribute to procedure complexity. Overall flyability may also be a factor for certain aircraft types. A Eurocontrol design guidance document emphasizes procedure validation to ensure flyability for all aircraft types intending to use the procedure.[12] Even when flyable, design factors may contribute to human performance issues if pilot workload is adversely impacted. Pilots have raised concerns about their ability to see Visual Flight Rules (VFR) traffic beneath them when maintaining exceptionally high climb gradients. These requirements are often imposed in noise-sensitive areas. Questions have been raised about achieving the proper balance between these factors and airspace management goals. Further dialogue and coordinated decision making amongst all participants are needed.

Several additional design attributes may contribute to path deviation events. Large course changes incorporated within the procedure may cause overshoot problems, especially when these waypoints are placed close to the departure end of the runway. Turns close to the runway can be problematic for aircraft still accelerating on climb-out. Speed restrictions have been shown to help alleviate this problem. Speed restrictions, however, may delay configuration changes after takeoff. Close-in waypoints may also be an issue for non-GNSS equipped aircraft, such as those using DME/DME systems. These systems take a specified time to update the aircraft's position once airborne. If this update hasn't yet occurred by the time the first waypoint is reached, an overshoot may occur. Procedure designers should consider these tradeoffs. Good progress in this area has been accomplished as lessons learned have been applied to new procedure designs.

Significant work is done to ensure that new RNAV procedures do not conflict with existing conventional ones. Nevertheless, an ASRS review revealed that traffic conflicts do occasionally occur as a result of disharmonized coordination between the two procedure types. Interference has also been mentioned relative to Military Operating Areas (MOAs). A review of specific issues may be warranted.

One observed pilot error can be traced to an RNAV procedure that shares a common name with a fix on another procedure. Pilots have mistaken clearance to the fix for clearance to fly the RNAV procedure. Several RNAV procedures may also share common initial segments with each other, causing some pilots to mistakenly select a different procedure.

Because RNAV procedures enable direct point-to-point navigation without depending on the location of ground-based navigation aids, they often incorporate a higher number of waypoints. This increase leads to a greater probability that two different waypoints will sound similar over the radio (such as "BRAZI" intersection and "Bradley" VOR) or that the waypoint name is unpronounceable. Examples of the latter issue include waypoints named “EVXAF” and “TEYYI”. These issues may lead to unexpected turns if the aircraft proceeds to an unintended waypoint.

FAA Orders 8260.46C[13] and 7100.9D[14] have been updated to provide some general human performance-related recommendations based on lessons learned. For example, both recommend limiting the use of fly-over waypoints. In addition, the RNAV Procedure Evaluation Team also considers some human performance issues when developing a new procedure. These efforts continue to improve an already high level of operational performance.

Even with these gains, it appears that procedure designers would benefit from a specific and comprehensive set of guidelines that concentrates on human performance. These guidelines could consolidate lessons-learned to date as well as incorporate any additional issues raised in human factors studies. Covered areas may include the use of speed restrictions, amount of course change, the number of course changes, and the proximity and number of successive altitude crossing restrictions. Incorporating these considerations into the design process could make it easier for designers to accommodate both air traffic and operational issues. In addition, this knowledge may be helpful to other countries implementing RNAV procedures.

### *RNAV Approaches*

Aircraft equipped with VNAV enable flight crews to fly a constant flight path angle descent from the final approach fix to the missed approach point, leading to more stable approaches when an electronic glide path would not otherwise be available. VNAV approach guidance is fundamentally different from the technique used to fly a conventional “non-precision” approach without a published glide path angle. A VNAV descent replaces the need to “dive and drive”, a process by which the aircraft descends and levels-off at each successive step-down fix. “Baro VNAV” aircraft incorporate the approach-specific glide path angle into the VNAV path when the approach is loaded.

When a VNAV glide path angle is used in place of progressive step-downs, operators may be approved to use a Decision Altitude (DA) in place of the Minimum Descent Altitude (MDA). Operators should ensure that pilots know whether this replacement has been authorized and the appropriate minima to use. In cases where a DA is not already published, some countries require an add-on to account for the dip below the DA that may occur when executing a missed approach.

RNAV approaches typically provide both LNAV MDA and LNAV/VNAV DA minima. To avoid potential confusion, it would be helpful for pilots to understand the rationale behind higher minima associated with the LNAV/VNAV DA. Although the approach with glide path offers higher precision and a more stable approach, it incorporates different obstacle clearance criteria under the United States Standard for Terminal Instrument Procedures (TERPS).[15]

A significant issue undergoing serious consideration within the RNAV community concerns the feasibility of designing an approach where DA is reached in a turn. This design choice would represent a considerable change from current operations where the missed approach point is always part of a straight segment and is normally aligned with the runway. Important questions to be addressed include the pilot’s ability to maintain adequate visual contact with the runway environment when reaching the DA. During a turning final segment, the runway will not align with the direction of flight. This offset may introduce perception issues when viewing the Visual Approach Slope Indicator (VASI), Precision Approach Path Indicator (PAPI), or the runway itself. Will pilots be disoriented when faced with this environment immediately upon exiting the clouds? Another concern relates to the aircraft response during the initial part of a potential go-around. When activated, the Takeoff Go Around (TOGA) buttons on older Boeing aircraft command a wings level flight attitude. This bank angle change could cause the aircraft to leave the desired flight path. Flight crew awareness and performance aspects will need to be evaluated.

Additional design issues include a potential maximum turn angle at the final approach fix and the length of the final approach segment. Both of these attributes contribute to the conventional definition of a stabilized approach.

### *RNP Approaches*

Tight linear containment regions and guaranteed path tracking performance associated with RNP enable procedure designers to construct published routes through highly constrained airspace environments. RNP greatly increases safety by aligning an aircraft's path tracking performance with the demands of a given procedure. With these new capabilities, traditional definitions of a "stabilized" approach are being reevaluated. Airlines have typically required that their aircraft be in straight flight at constant flight path angle and thrust setting and in final configuration while on the final approach segment. Deviation from these conditions would require an immediate missed approach. RNP procedures offer the opportunity to design segments that incorporate curved paths and changing flight path angles. This flexibility enables procedure designers to make the most use of available airspace and to achieve the lowest possible minimums. Along these lines, a new definition of "stabilized approach" has been proposed: "an approach where the aircraft is in the landing configuration and the lateral and vertical trajectories are managed by the automation system and predictable to the operator." Whether or not this new definition or some variant is acceptable to the airline community and to regulators is a subject of future discussion.

Several turning segment issues are under consideration for RNP approaches. The "DA in a turn" issue discussed for RNAV approaches is also applicable to RNP procedures. Questions exist concerning the requirement for a straight segment before and after DA. If a straight segment is required, how long should it be? Additional questions concerning turning segments include the appropriate minimum altitude for a turn, the minimum altitude for the aircraft to be aligned with the runway centerline, and the proper length of straight segments that precede Radius to Fix (RF) legs on final approach. Aircraft flying at higher approach speeds will have a more difficult time complying with tight turn radius requirements for RF legs. A method is needed to ensure these limits can be met for all aircraft that may fly the procedure. FAA documents such as Order 8260.52[16] provide guidance to procedure designers on these areas. Human performance studies are ongoing to explore evolution of these criteria for turning segments.

ARINC 424 publishes numerous leg types and path terminators.[9] Certain leg types may be more susceptible to the FMS design variation discussed above. To ensure acceptable path conformance for all aircraft types using the procedure, guidelines are needed for design decisions such as the use of a particular leg type or the choice of one over another. Nonetheless, several members of the airline community have concerns that procedures designed for "lowest common denominator" equipment do not allow those airlines with more sophisticated FMS/RNAV systems to get full use out of their capabilities.

During the initial implementation of RNP, all RNP operations were customized for each particular airline. The overall operation included aspects such as the procedure design, flight crew training, use of automation, and checklists. RNP operations were designed to accommodate an airline's unique fleet type, operational procedures, and particular airports served. As procedures are now being implemented for public use (subject to Special Aircrew and Authorization Required [SAAAR]), it will be necessary to ensure they are designed in a way that accommodates all airlines and aircraft that may use them. These public procedures must be able to accommodate multiple flight deck platforms, FMS types, and flight crew procedures. Procedure design and operational guidance are currently provided by FAA documents such as Order 8260.52[16], AC 90-101,[17], AC 120-29A,[18] and individual airline "Op Specs". Some highly complex procedures may need to remain airline-specific. Criteria are also needed to support this decision.

### *RNP Parallel Approach Transition (RPAT)*

RPAT is an operational concept currently under development and evaluation. It involves simultaneous parallel runway operations with one aircraft flying an ILS approach and the other conducting an RNP procedure. RPAT is conducted in weather conditions sufficient to allow the RNP aircraft to visually acquire the ILS traffic before crossing the final approach fix. The RNP traffic must execute a missed approach if it doesn't have the ILS traffic in sight by this point. A potential human performance issue relates to the ability of the RNP aircraft to consistently acquire the ILS traffic while conducting its own approach under marginal VFR weather conditions.

### *En Route Procedures*

In general, pilot workload doesn't present as many challenges to designers of en route procedures as it does to those supporting the terminal area. Nonetheless, en route procedures such as Q routes and FMS offsets should be designed to allow adequate fallback options if a system failure or other condition prevents the procedure from being flown as intended. Radar procedures generally provide risk mitigation for these operations.

## Charting

To this point, discussion of RNAV procedures has related to operational and equipment aspects for pilots and controllers. Representation of these procedures onto paper or electronic media also encompasses a number of human performance-related issues.

When required information elements are added to RNAV SIDs and STARs having multiple paths and flight segments, the resulting charts can become cluttered. In turn, clutter can create the appearance of higher complexity. These charts can cause excessive search time, higher workload, and an increased chance of an interpretation error. A chart that has limited white space can be difficult to read and locate important pieces of information.

Chart clutter can be attributed to a number of different factors. It may be the result of an overly complicated procedure design, an abundance of required information elements, or inefficient use of available space. It may be helpful to review current procedures to ensure they achieve the proper balance between air traffic and operational needs. Specific attention to charts that incorporate many of the design attributes discussed above may be warranted. In many cases, it appears that traditional rules for providing some types of information and apparently trivial distinctions can seriously impact an RNAV chart. For example, one RNAV SID depicts four heading to altitude waypoints in close proximity. All four waypoints give an altitude where the turn should be initiated that is within 20 feet of a cardinal altitude. Because of this seemingly insignificant distinction, separate arrows and altitude text boxes must be provided. In other cases, a long laundry list of low height obstacles takes up valuable chart real estate. These obstacles are often well off the charted path and do not appear to present an operational hazard. To accommodate this issue, it may be necessary to revisit some existing protocols for providing these types of information.

Lack of display "real estate" can lead to other problems. Without sufficient space, chart designers often must resort to putting information where they can find an available spot instead of a more optimal or consistent location. Altitude crossing restrictions for some charts have been placed well away from the waypoint they represent. In addition, busy charts often necessitate the use of extremely small font size. It's questionable whether some information can be readily retrieved from charts under challenging conditions such as at night or in turbulence.

It may be beneficial to re-consider chart formatting techniques in cases where there's no compelling visual difference between two symbols or text boxes that have an important distinction. For example, it may be difficult to immediately distinguish between text boxes that indicate "at or above" or "at or below" altitude restrictions. In an ASRS review of RNAV SIDs in Las Vegas, pilots often failed to notice an unconventional at or below altitude restriction. This restriction is necessary to keep departures separated from incoming arrivals.

Chart formatting may lead to confusion when different formats are used to describe the same thing. For instance, one chart source has two different ways to indicate an altitude crossing restriction. It's depicted as "cross at" followed by the altitude on some charts and as an altitude with a bar above and below it on others. For some charts, inconsistencies have also been observed between the depicted procedure and the corresponding textual description.

In other cases, the choice of wording on a chart may lead to confusion. A recent issue emerged in Atlanta when pilots misinterpreted instructions for "aircraft departing north" to mean aircraft that are flying to a destination north of Atlanta. Instead, the instructions were meant to apply to aircraft departing the local Atlanta area on an initial northerly heading. This problem could probably be addressed with a simple wording change.

Wording choice has also been raised as a potential source of confusion for RNAV approaches. These charts currently provide “LNAV” and “LNAV/VNAV” minimums. “LNAV” and “VNAV” also describe autoflight modes on some aircraft. Use of the same abbreviators to refer to two different things could cause confusion. It may also provide an unintended link between a charted procedure and a particular type of equipment.

Several concerns relate to the use of “LNAV/VNAV NA” in the minimums line. Pilots have interpreted this notation to mean that use of VNAV is not authorized on the approach. On some charts, this notation is used even when a final approach flight path angle is depicted. In these cases, it appears that the procedure can’t be flown as depicted. Even without a published glide path angle, pilots are allowed to use VNAV provided they remain at or above the step-down altitudes. In actuality, RNAV Task Force discussion revealed the notation only means that LNAV/VNAV minima are not available. It doesn’t limit the use of VNAV for the approach. Similar confusion has resulted from use of “LNAV/VNAV” with a corresponding blank line.

RNAV equipment is often an allowable substitute for sensors that rely on ground-based navigation aids. One chart note, “ADF Required”, can be confusing for operators with equivalent capability. It’s been suggested that this note be changed to “ADF or equivalent capability required”. This case may be an example of a conventional note that has not kept pace with the proliferation of new allowances for RNAV capabilities.

Many RNAV SIDs have a “top altitude”. This altitude represents the vertical clearance limit for the procedure. It is often the altitude limit provided to pilots on their initial clearance. Confusion can arise when an altitude crossing restriction on the procedure is greater than the top altitude. In this case, it appears that the chart is internally inconsistent and cannot be flown as depicted. This disparity can cause concern when pilots are unaware of the reason behind the crossing restriction. One example of this issue occurs on a Las Vegas RNAV SID. In a discussion, FAA personnel indicated that a restriction is needed to ensure DME coverage for DME/DME aircraft. It’s not needed to maintain terrain clearance.

It may be possible to use charted procedure supplements to make pilots aware of general information that encompasses operational, equipment, and charting aspects of RNAV procedures. One suggestion under consideration would provide a departure operations page at the beginning of each set of RNAV SID and STAR procedures for a given airport. This page could cover general areas such as the need to ensure proper FMS programming as well as any specific local issues.

Human factors experts have provided some recommendations for chart designers of RNP approach procedures. These charts should be consistent, have minimum clutter, be readable, and support planning. Along these lines, it is recommended that a chart’s textual description depict waypoint fly-by/fly-over status. It may also be helpful to depict flight track graphically for some leg types.

Chart depiction is often rooted in the procedure design itself. Nevertheless, charts play a substantial role in ensuring that pilots understand the procedure, are able to readily extract necessary information, and fly it as intended. Development of both procedure and chart design guidelines would help to achieve these goals.

## Chart/Database Commonality

Consistent representation of procedure information between the FMS navigation database and the chart is essential to mitigating excessive flight crew workload and potentially hazardous operational errors. This issue gained international prominence after the crash of American Airlines Flight 965 in Cali, Colombia on December 20, 1995.[19]

While approaching Cali, the flight crew intended to program the ROZO NDB (located near the airport) into the FMS. On the chart, this fix is identified by the letter ‘R’, but the navigation database recognizes it as ‘ROZO’. When the crew programmed ‘R’ into the FMS (instead of “ROZO”), the database loaded the ‘ROMEO’ NDB into the active flight plan. ‘ROMEO’ is another NDB well off course to the east that is also indicated by the letter ‘R’ on the chart. The resulting route took the aircraft off the intended path and it impacted terrain. In response to this accident, the NTSB recommended that approach charts, FMS navigation databases, and electronic map displays provide a consistent representation of navigation information.[20]

Discrepancies between charts and databases continue to exist today. Some fixes on the chart are still not the same as the corresponding fix in the database. One example of this type of discrepancy exists when DME fixes are used as step-downs on an approach. The chart may only list the DME distance at each point because a waypoint name has not been established. In order to store these fixes in the database, the navigation data supplier must choose a name. Pilots looking at these fixes on both the map display or FMS Legs page and the chart will see different representations of the same point.

When multiple approaches of the same type exist to the same runway and airport, the FAA and ICAO append a “multiple indicator” (-Z, -Y, etc.) to the approach name. These indicators start from the end of the alphabet, with one letter being assigned to each approach. Their use has become more prevalent as RNAV approaches have been added. Because the multiple indicator is a recent addition to ARINC 424, many flight management systems are not yet able to accommodate it. When using these systems, pilots won’t necessarily know which approach that has been loaded. The procedure name shown on the FMS Procedures page will not match the approach name indicated on the chart. Criteria are needed to establish a specified approach in the series that will load by default when the pilot selects an approach for a runway containing multiple procedures of the same type. This default must be mutually understood between the pilot, operator, and navigation data provider. As an alternative, some are proposing a reduction in the number of common type approaches to the same runway. For example, multiple RNP-based approaches with a common missed approach segment could be incorporated into a single chart incorporating different minima for each supported RNP level.

FMS navigation databases can also be used to provide supplemental information for most conventional procedures. A FAA notice recommends that operators pay particular attention to their flight track when using FMS guidance for non-RNAV procedures.

## Approach Naming and Approach Classification

Most instrument approaches are currently named based on the sensor equipment that supports them. This convention has led to the proliferation of approach names including ILS, VOR, NDB, LOC, LDA, SDF, and many others. This naming convention appears to be inconsistent with a performance-based environment that intends to focus on capabilities rather than the types of equipment used. The vast number of approach types can lead to complications for airlines needing to provide training and proficiency opportunities for their pilots.

The current approach classification system can lead to confusion when pilots must determine how new technologies on their aircraft fit into the regulatory structure of existing conventions. Approaches have historically been grouped into broad classifications that specify general characteristics of the type of guidance they provide. This classification includes two types: “precision” and “non-precision.” These definitions are still officially recognized by ICAO and remain embedded in FAA regulations. Precision approaches such as ILS and GNSS Landing System (GLS) are required to meet certain ICAO requirements for a vertical glide path. “Non-precision” approaches have traditionally only provided lateral guidance. Approaches with vertical guidance incorporating other GNSS-sensor supported glide paths (such as Wide Area Augmentation System (WAAS)) or non-GNSS Baro VNAV systems do not qualify as “precision”.

Discussion is underway to consider changing this classification system to one that is more intuitive for all users and more inclusive of new technologies. Concatenation of current approach types into a system that focuses on RNAV, RNP, and “xLS” may enable a more dedicated focus to the operational capability offered by each approach type. The term “xLS” refers to an approach type that supports an autoland capability (such as ILS, MLS, or GLS).

A more direct relationship between an approach type and its derived minima is another potential benefit of a new classification system. One example of the lack of connection between legacy approach types and operational capability is the prevalence of RNAV approaches with higher LNAV/VNAV minima than those offered by traditional approaches to the same runway. A re-classification should enable operators to derive more utility from their equipment investments, while affording greater overall simplicity.

The FAA and some manufacturers have already taken steps to phase out the older definitions. FAA AC 120-29A explicitly avoids the terms “precision” and “non-precision”.[18] It provides a new classification system consisting of 3 areas: “xLS”, “RNAV”, and “Instrument Procedures Other Than xLS or RNAV.” These descriptors are more closely aligned with associated levels of navigation performance capability. Currently, only xLS is authorized for Category II weather minima (not lower than 100 ft).[18] “RNAV” includes provisions for different levels of RNP and can be further broken down into 3D (LNAV/VNAV) and 2D (LNAV). The “Other” category includes traditional procedures such as VOR and NDB and applies when they are flown using raw navigation data from the named sensor system.

Organizations and committees such as the International Air Transport Association (IATA) and the All Weather Operations Harmonization Working Group (AWO HWG) are also supporting changes to existing ICAO definitions. One such proposal for the near to mid-term aligns with the AC 120-29A definitions. Eventually, this classification may be further simplified to 3D (xLS, RNAV (RNP), and RNAV with LNAV/VNAV minima) and 2D procedures (those using an MDA).

With these potential benefits in mind, there are also a number of considerable challenges that result from ongoing efforts to change the approach classification system. The legacy system is internationally established and is widely distributed across a range of documentation, regulations, and operational procedures. Some affected areas include training documents, airport lighting, airspace protection, obstacle assessment, airspace design, and alternate minima requirements. Some have raised concerns about a potential classification change. One FMS manufacturer raised the possibility that a re-classification of VNAV approaches under a higher category could require the FMS to be certified at a more stringent level, thereby increasing costs. If such a change is to be considered, a comprehensive effort to determine all areas affected by the current system would clearly be needed.

## Flight Plan Suffixes

Controllers must rely on single letter codes (flight plan suffixes) to determine whether an aircraft meets the requirements for performing a particular operation. FAA and industry representatives have raised concerns that current flight plan suffixes do not meet the needs of a performance-based navigation system. Comparable to the current approach naming convention, these suffixes normally indicate the equipment on board an aircraft rather than an available capability. Although some of these suffixes directly relate to a capability (such as those referring to Reduced Vertical Separation Minima (RVSM)), many of them only indicate the type of equipment onboard. Controllers must then determine whether an operation can be performed based on the presence of certain types of equipment. They often lack sufficient information to make this assessment. When clearances are issued for an operation that an aircraft cannot support, workload is increased for both pilots and controllers. In these cases, controllers must often work out a new plan that involves a different procedure and flight crews must review and re-program that procedure. These problems also occur when the ATC host computer assigns a procedure to a flight plan that the aircraft cannot support.

These issues are likely to become more common as the number of equipment combinations and operational capabilities continues to increase. The proliferation of different RNAV and RNP procedures may quickly overwhelm the capability of controllers to make reasonable assessments of aircraft capability based on the current suffix system. For example, some RNAV approaches do not allow the use of DME/DME. Aircraft with /E or /F equipment are not allowed to fly “GPS” Approaches.[18] There is also no direct correlation between a current flight plan suffix and the ability to fly a Q route. A single suffix is currently used to indicate RNP capability. RNP requirements vary between some procedures and there is no means for a controller to determine an aircraft's RNP level. Changing to an approach classification system where a single procedure is used for multiple RNP levels would alleviate this problem.

Flight plan suffix ambiguities also extend to pilots and operators. Pilots must be aware of their ability to accept an assigned procedure. Confusion with an equipment-based suffix system can also exist when a particular piece of equipment doesn't align with those referenced in the suffix list. Past FAA documentation indicates that some operators have mistakenly taken /F credit (indicates FMS capability) when equipped with only an Attitude Heading Reference System (AHRS). The AHRS does not provide a path tracking capability that meets FMS standards.

Although recently changed to recognize RVSM capability, the current flight plan suffixes are likely inadequate to meet the needs of a performance-based NAS. These limitations will become more apparent as performance-based operations extend to communication and surveillance capabilities as outlined by the JPDO.[4] Steps taken to re-structure the flight plan suffixes should be internationally coordinated as U.S. and ICAO suffixes currently do not align.

### NOTAMs

Pilots have long raised concerns over the ability of the NOTAM system to effectively disseminate timely information. NOTAM information can be difficult to access and its format is often hard to read and understand. Important NOTAMs are often embedded in a long list of items having less apparent operational significance. For example, pilots have voiced opposition to including extensive lists of low height obstructions far from any likely path. This "low signal to noise ratio" can cause aircraft operators and pilots to miss important information.

In a performance-based NAS, NOTAMs will increasingly be used to inform pilots about degraded capabilities of key navigation infrastructure. They may also be needed for aircraft system-related problems such as navigation database errors. The dynamic nature of this information will likely place even higher demand on efficient and accurate information retrieval.

As RNAV and RNP procedures are evolving, the NOTAM system should be reviewed for its ability to provide sufficient supporting information that allows pilots to make operational decisions. A specific concern relates to the information available if the Department of Defense degrades the GPS signal. NOTAMs must be able to provide pilots and operators with the proper information in a format that can be readily accessed.

## Issues List Prioritization

### Prioritization Criteria

Priority assignments (high, medium, and low) are provided for each issue listed in Appendix A. The priorities were assigned based on the following criteria:

- Level of importance assigned by the PARC Human Factors Working Group. This working group assigned attributes of the most important issues during a July 2005 Working Group meeting. Issues identified as important included those that
    - have been asked for by a PARC working group or action team;
    - support regulatory material development;
    - address a significant safety issue in the implementation of performance-based airspace;
    - and those where an opportunity exists to affect change in a timely way.
- Prevalence of issues mentioned in various forums.
- Existence of broad-reaching impact considered fundamental to performance-based navigation.
- Level of importance assigned by expert users during interviews.

In general, if an issue rated highly in any of these factors, it was given a "high" rating.

If no attribute emerged as being particularly strong, it received a "medium" rating. Issues that were considered applicable to a smaller group of users and deemed to have only minimum consequence received a "low" rating. New thrusts in the RNAV/RNP community or the development of new operational procedures could potentially change the ratings. A total of 259 issues were identified: 144 high, 96 medium, and 19 low.

## Recommendations for Earliest Consideration

Several high-rated issues are recommended for near-term studies by government/industry committees and research organizations. For these issues, answers to important human factors or design questions are desirable in order to further improve overall operational performance and mitigate error.

### *Human Factors Guidelines for RNAV/RNP Instrument Procedure Design*

It appears that procedure design techniques are currently based primarily on obstacle clearance assessments, minimum reception altitudes, noise restrictions, and traffic flow management issues, with less emphasis being placed on operational human factors. Eurocontrol's design document emphasizes the flyability of RNAV terminal area procedures and clarifies it is not intended to directly address operational issues.[12] Changes to FAA Orders 8260.46C[13] and 7100.9D[14] pertaining to SIDs and STARs do provide some awareness of human performance issues based on lessons learned.

Terminal area and approach procedure designers would likely benefit from a set of comprehensive and specific design guidelines that consider flight crew and controller performance. These guidelines could be used as part of an overall package evaluated prior to the development of a new RNAV procedure. They could also be applied to current procedures, with recommendations made for improvement. Guidelines should consider the human performance effects of design attributes discussed in this report and the accompanying Issues List. Attributes include but are not limited to climb gradients, waypoint proximity, the use of successive altitude restrictions, and DA in a turn. They should also consider ways for common elements between similar procedures at an airport to be evaluated for their potential to cause misidentification (capture) errors.

The guidelines should be supported by a series of studies that identify tradeoffs between different design techniques, propose recommended limits, and consider interaction effects.
An assessment should be made of current design techniques for their impact on human performance.

Considering the negative effects of high overall complexity, a study is recommended to develop a procedure complexity metric. FAA Orders 8260.46C[13] and 7100.9D[14] mention the importance of low complexity but do not seem to offer a specific metric. An effort should also be made to assess the effects of common design techniques and their interactions on overall complexity. Recognizing that different airports present various design challenges, a review process is recommended for procedures that exceed a defined complexity threshold.

### *Identification of Lessons Learned during RNP SAAAR Experience and Recommendations for Implementation of Public RNP Procedures*

Considerable operational experience has been obtained by airlines that currently fly specially-tailored RNP procedures. These procedures as well as procedures proposed for public use fall under the category "Special Aircraft and Aircrew Authorization Required (SAAAR)". Some companies such as Naverus specialize in developing tailored RNP procedures for airline customers. An effort should be made to ensure that recommendations for transitioning toward public RNP procedures capture lessons learned from prior experience in RNP procedure design, flight crew operations, and training. These recommendations should also include complexity guidelines that may require the procedure to be used only when specially designed for an airline or other operator. Procedure design recommendations can be used to support the broader effort on RNAV/RNP procedure design guidelines discussed above.

### *Continuation of and Coordination among Working Groups that Identify and Propose Solutions for Operational Problems Associated with RNAV SID/STAR Procedures*

A number of highly beneficial activities are currently ongoing in various working groups to identify and mitigate operational problems that have occurred on some RNAV SID and STAR procedures. The RNAV Task Force, RNAV Procedure Evaluation Team, PARC, and ICAO are examples of groups supporting these activities. These groups consist of a broad spectrum of NAS stakeholders, including pilots, controllers, navigation data providers, avionics and airframe manufacturers, and government agencies. Efforts are currently underway to conduct human factors studies to consider the effects of proposed new ATC terminology as well as to recommend targeted areas for pilot and controller awareness. Included in these activities are implementation studies of "climb via" terminology and consideration of ways to inform pilots and controllers about issues associated with runway change assignments. Strong collaboration among groups addressing these issues is needed to ensure harmonized solutions and effective allocation of resources.

### *Consideration of Potential Changes to Approach Naming, Approach Classification, and Flight Plan Suffixes*

A coordinated effort should be undertaken to consider the potential benefits and impact of a significant change to the approach naming, approach classification, and flight plan suffix systems. The group undertaking this project should have representation from the full spectrum of NAS stakeholders. It is recommended that this process begin with a detailed assessment of perceived problems associated with current day systems. It should also provide a comprehensive list of all documents, training programs, regulations, procedures, and any other areas that would be affected by a potential change. Considering the problem and impact assessments, an analysis of different change options could be undertaken. If the group determines that a change is warranted, it could consider working through existing committees to submit a proposal to ICAO. As noted earlier, ICAO is currently considering some proposals in these areas.

### *Resolution of High Priority Items Concerning Chart/Database Commonality*

The FAA and data suppliers should continue work to resolve differences between navigation databases and published charts. High priority should be given to specific recommendations issued by the NTSB. One presentation from a data supplier indicated that more assistance from the FAA is required in order to address some of these recommendations. Assignment of waypoint names to DME fixes used on instrument approach charts has also been identified as an important issue.

### *Review of Aircraft Equipment-Related Impact of RNAV and RNP Operational Events*

A comprehensive review of problematic operational events attributed to equipment-related factors should be undertaken for RNAV SIDs and STARs, RNAV approaches, and RNP approaches. Consideration should also be extended to cases where the absence or non-use of a particular system may have played a role. If this review reveals common deficiencies, the FAA should consider revising the appropriate documentation.

In this review, the use of electronic map displays for RNAV/RNP should receive particular attention. NASA's preliminary review of RNAV SID/STAR procedures found that pilots often mentioned the lack of a map display as a contributing factor to high workload and error conditions. FMS interface, display, and alerting issues should be considered. The effect of flight management systems to handle particular leg types and path terminators on flight crew performance and procedure design would also be of interest. Many of these factors are being discussed by the Flight Deck Automation Working Group.

### *Review of Issues Pertaining to Use of Baro VNAV during Instrument Approaches*

Airlines have found that the use of electronic glide paths provided by Baro VNAV leads to more stable approaches, higher precision, and lower pilot workload. Considering these advantages, two primary issues emerged related to the use of Baro VNAV for instrument approach procedures: selection of appropriate decision altitudes and terminology used on the LNAV/VNAV minima line. It would be beneficial for procedure designers to compare established minima for existing non-precision approaches with those of comparable LNAV/VNAV minima for RNAV approaches. In government/industry meetings, several members of the airline community were unclear of the rationale for establishing higher minima for LNAV/VNAV supported approaches than those in place for current non-RNAV approaches without vertical guidance. Any inconsistencies in minima application should be clarified or resolved.

Efforts should be taken to review and clarify the use of "NA" or a blank space on the LNAV/VNAV minima line for RNAV approaches. Several airline committee members have stated that this usage leads pilots to believe that VNAV is not authorized for the approach. This confusion may prevent pilots or operators from taking advantage of the safety and performance benefits associated with Baro VNAV.

### Selection of Targeted Studies

When considering a particular area of concentration for more detailed study, researchers, industry representatives, and government officials should consider a number of different factors. Among these factors include the existence of ongoing studies, current priorities, available resources, and time available. In some cases, it may be advantageous to consider bypassing a significant, broad-reaching issue that will require substantial resources in favor of one that has somewhat less impact, but can be greatly mitigated with a smaller-scope effort.

Availability of necessary infrastructure and personnel are also likely to be major factors when considering targeted studies. Issues that require a detailed assessment of flight crew performance will necessarily require high fidelity simulators that are able to replicate observed or anticipated operational challenges. For example, the "DA in a turn" issue described above will require a flight simulator that has highly realistic visual effects. Motion may also be required in order to simulate potential interactions between visual and sensory perception. Issues relating to controller phraseology will certainly require the participation of air traffic personnel.

In many cases, proper treatment of an issue will require joint efforts from a diverse group of specialists. For example, efforts to produce recommended guidelines for instrument procedure design should at least include pilots, air traffic controllers, procedure designers, and regulators. Each group will bring a different perspective, thus enabling the group recommendations to properly balance the needs of all parties.

Any effort to address a human factors issue should only be undertaken after careful review of ongoing work by other government/industry committees and research organizations. After starting such an effort, the community would likely benefit from remaining apprised of the latest operational trends and the continued relevance of the issue under consideration. Advancements in system capabilities or operational procedures may change the characteristics of an issue. These changes may require the study to shift focus.

## Conclusions

A substantial transformation to a performance-based navigation system is underway worldwide. New RNAV and RNP procedures are being developed and implemented at a rapid pace. Benefits offered by these procedures are extensive and are being realized by both operators and air traffic service providers. The prevalence of these benefits suggests that the transition toward a performance-based system will continue. The initiation of these new procedures has caused several human performance issues to emerge. These issues have been linked to fundamental changes in air traffic operations from both a pilot's and controller's perspective as well as design challenges that have been placed on aircraft systems that must accommodate the changes. Additional human factors issues are associated with proposed new applications of RNAV and RNP procedures. To ensure a seamless transition to performance-based navigation, a collaborative effort between all stakeholders is needed to mitigate issues when they come up in service and to anticipate potential issues before introduction of new operations.

A strong desire to realize the benefits of RNAV and RNP is leading to a dynamic environment where issues are observed, brought to the attention of government/industry groups, and addressed in targeted studies. There are currently a number of different working groups that are considering issues such as those raised in this report. These groups include those sponsored by the FAA, ICAO, and the Joint Aviation Authorities (JAA) in Europe. As issues are addressed by these diverse groups, there is a strong need for communication and collaboration to ensure consistent findings and to avoid duplication of efforts. It would be highly desirable that approaches taken to resolve these issues be globally compatible. Coordination between groups would facilitate consensus on issue prioritization and would conserve valuable resources.

Effective worldwide coordination on issue prioritization and investigation is a lofty overall goal. Results of this study suggest that even relatively smaller coordination efforts along the way can also yield significant benefits. Small groups of technical experts from different fields have developed effective solutions to issues that occurred during operational service. Development of instrument procedure design criteria based on human performance considerations would likely provide a better link between the operational community and the procedure designers.

This report and the accompanying Issues List have provided an initial assessment of various human factors issues arising from the transition to a performance-based navigation system. Due to the dynamic nature of this subject matter, recommended areas for more detailed consideration are expected to evolve significantly as new procedures are implemented and greater system capabilities are achieved. It is likely, however, that these new issues will continue to have common features with those raised in this report.

## References

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[4]Joint Planning and Development Office, “Next Generation Air Transportation System Integrated Plan,” Department of Transportation, Washington, DC, 2004.

[5]FAA, “U.S. Terminal and En Route Area Navigation (RNAV) Operations,” AC 90-100, Washington, DC, 2005.

[6]Barhydt, R. and Adams, C., “Human Factors Considerations for Area Navigation Departure and Arrival Procedures,” 25th ICAS, Hamburg, Germany, 2006.

[7]FAA, “Air Traffic Control,” Order 7110.65R, Washington, DC, 2006.

[8]FAA, “Aeronautical Information Manual,” Washington, DC, 2006.

[9]Aeronautical Radio Incorporated, “Navigation System Data Base,” ARINC 424-17, Annapolis, MD, 2004.

[10]Ottobre, R., O’Neill, J., and Herndon, A., “Analysis of Advanced Flight Management Systems (FMSs),” MITRE, http://www.mitre.org/work/tech_papers/tech_papers_05/05_0894/index.html, 2005.

[11]FAA, "Acceptance of Data Processes and Associated Navigation Databases," AC 20-153, Washington, DC, 2005.

[12]Eurocontrol, "Guidance Material for the Design of Terminal Area Procedures for Area Navigation (DME/DME, B-GNSS, Baro-VNAV & RNP-RNAV)," Edition 3.0, 2003.

[13]FAA, "Departure Procedure (DP) Program," Order 8260.46C, Washington, DC, 2005.

[14]FAA, "Standard Terminal Arrival Program and Procedures," Order 7100.9D, Washington, DC, 2003.

[15]FAA, "United States Standard for Terminal Instrument Procedures (TERPS)," AC 8260.3B Chg 19, Washington, DC, 2002.

[16]FAA, "United States Standard for Required Navigation Performance (RNP) Approach Procedures with Special Aircraft and Aircrew Authorization Required (SAAAR)," Order 8260.52, Washington, DC, 2005.

[17]FAA, "Approval Guidance for RNP Procedures with SAAAR," AC 90-101, Washington, DC, 2005.

[18]FAA, "Criteria for Approval of Category I and Category II Weather Minima for Approach," AC 120-29A, Washington, DC, 2002.

[19]Aeronautica Civil of the Republic of Colombia, "AA965 Cali Accident Report," http://sunnyday.mit.edu/accidents/calirep.html, Bogota, Columbia, 1996.

[20]NTSB, "NTSB Recommendations A96-90 through -106," http://www.rvs.uni-bielefeld.de/publications/Incidents/DOCS/ComAndRep/Cali/cali-ntsbrec.html, Washington, DC, 1996.

# Appendix A: Human Factors Issues List

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 1 | Technical Interchange Meeting | Terry Stubblefield | FAA | Airline Procedures | | | High | Different operator philosophies relating to use of automation and flying instrument procedures. Some standardized procedures may be needed to ensure adequate path adherence. |
| 2 | RAT #NAV01.2 /PaRC | Greg Tennille/ Bill Vaughn | MITRE/ Continental Airlines | Airline Procedures | | | Medium | Lateral and vertical path navigation engagement height above departure end of runway/airport elevation varies between operators/equipment, which can influence path tracking performance and adherence to altitude constraints. AC 90-100[5] provides guidance on this procedure. |
| 3 | RNAV Task Force | Brian Will | American Airlines | Airline Procedures | ATC Procedures | | High | Some would like to see expected runway information in PDC. Brian Will raised concern that information in PDC will make it seem like a clearance. |
| 4 | PARC Human Factors WG | Ken Speir | Delta Airlines | Airline Procedures | ATC Procedures | Training | High | Flight crew training should emphasize the importance of verifying that correct runway is loaded into FMC during RNAV/RNP operations. Various means were discussed to help ensure accuracy, including allowing non-movement time after a runway change and a possible verification of loaded runway with ATC. ATL and DFW airports currently addressing this issue by having controllers ask pilots to verify their programmed route. Due to ATC workload considerations, alternative solutions are being discussed. |
| 5 | ASRS Review | Richard Barhydt | NASA | Airline Procedures | Equipment Capabilities | | Medium | Company filed for RNAV procedure when airplane not properly certified. |
| 6 | AC 90-100 | | FAA | Airline Procedures | Equipment Capabilities | | High | Operators must develop procedures to verify correct GPS operation if GPS system unable to alert pilots to loss of signal during procedure requiring GPS. Are these procedures adequate and straightforward? |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 7 | ASRS Review | Richard Barhydt | NASA | Airline Procedures | PDC | | Medium | Discrepancies have occurred between the controller understood clearance and PDC information. |
| 8 | Checker 5 SID @ KCLT report; | | FAA | Airline Procedures | PDC | | High | RNAV SID filed by dispatch different than assigned via pre-departure clearance (PDC). Not detected until ready for takeoff and received different clearance. Did PDC format contribute to this event? |
| 9 | ASRS Review | Richard Barhydt | NASA | Airline Procedures | PDC | Flight Crew Procedures | High | Important information sometimes embedded in pre-departure clearance (PDC). Problems have occurred when route changes aren't highlighted and go unnoticed. |
| 10 | Pilot Deviations Report | | NASDAC | Airline Procedures | PDC | Flight Crew Procedures | High | Flight crew fails to notice that PDC departure clearance differs from their expectation. Crew flies wrong procedure. |
| 11 | RNAV Task Force | Dave Nakamura | Boeing | Airline Procedures | RNP Approaches | | Low | A proposed new entry for an RNP hold procedure may lead to pilot situation awareness issues. The new entry may impact how the track is depicted on the navigation display. Pilot training is proposed. |
| 12 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | Airline Procedures | Training | | High | FMS capability varies among air carriers and corporate operations. Training programs for using FMS and proficiency sessions should be implemented. |
| 13 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | Airline Procedures | Training | | High | Glideslope vs. glidepath should be understood and training/guidelines should be proposed to prevent descent below stepdown fix altitudes. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 14 | Technical Interchange Meeting | | Southwest Airlines | Airline Procedures | Training | Flight Crew Procedures | Medium | Cross aircraft model flying in single shifts impacts pilot performance on procedures due to differences in capabilities of equipment. Aircraft changes can cause input errors, deficiencies in transfer of mental model of equipment functioning from one a/c to another. |
| 15 | CHECKER 5 report | | FAA | Airline Procedures | Training | Flight Crew Procedures | High | Familiarity with procedure different for crews who fly RNAV procedures regularly and those who don't. Less recent experience can lead to confusion and interpretation errors. Training and proficiency sessions may be needed for flight crews with less recent experience. |
| 16 | ASRS Review | Richard Barhydt | NASA | Airline Procedures | Training | FMS (other) | High | Some flight crews are not properly trained in FMS or RNAV operations, resulting in path deviation errors and high workload when conducting RNAV procedures. |
| 17 | RNAV Task Force | Ted Demosthenes /Bill McKenzie | /Boeing | Approach Naming and Approach Classification | | | High | Current approach classification system is deemed to be inadequate. Recommendation that proposed new approach classification system should be performance-based, related to derived minima, independent of aircraft size and type and focus on operations (not technology). One approach calls for distinction between approaches with vertical guidance and those without vertical guidance. Factors complicated by current classification system include airport lighting, airspace protection, obstacle assessment, training, airspace design, alternate minima, and others. |
| 18 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | Approach Naming and Approach Classification | | | High | Instrument approaches are currently named based on the specific navigation used to fly the approach. This system has led to proliferation of instrument approach types. Approach names should be based on navigation performance, not on sensor type. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 19 | RNAV Task Force | Operations Panel | ICAO | Approach Naming and Approach Classification | | | High | Recommended guidelines for new approach and landing classification system: based on stabilized final approach, performance-based, related to derived minima, encompass a number of approach types, capable of seamless introduction into existing documentation, and independent of aircraft size and type. |
| 20 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | Approach Naming and Approach Classification | | | High | The current approach classification system (precision/non-precision) is inadequate for RNAV/RNP. The classification system should be updated. Any changes will need to be considered in light of proliferation of these terms in other documents (training, regulations, etc.) |
| 21 | FAA RNP KSN site | Terry Stubblefield | FAA | Approach Naming and Approach Classification | Airline Procedures | | High | The current approach classification system is based on equipment, not on capabilities. Use of performance-based criteria can reduce the number of categories, thereby reducing training and currency requirements. |
| 22 | RNAV Task Force | | Smiths Industries | Approach Naming and Approach Classification | FMS (other) | | High | Concerns were raised that re-classification of FMS approaches as "precision" could require FMS to be certified at higher level (expensive). |
| 23 | PARC Human Factors WG | PARC Human Factors WG | PARC Human Factors WG | Approach Naming and Approach Classification | FMS Nav Database | | High | No RNP approach type designation in ARINC 424. Recommendation to distinguish between RNAV (GPS), RNAV (RNP), etc. |
| 24 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | Approach Naming and Approach Classification | Procedure Design | | Medium | Why are there lower minima for existing non-precision approaches when compared to LNAV/VNAV line on RNAV approach? |
| 25 | Technical Interchange Meeting | John Anderson | Continental Airlines | Approach Naming and Approach Classification | RNP Approaches | | High | Confusing to have more than one RNP approach to same runway (currently done with X, Y, Z, etc.) distinction. These variations may have different missed approaches. Would be better to have a single RNP approach with different minima corresponding to different RNP levels. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 26 | RNAV Task Force | Jeff Williams | FAA | ATC Procedures | | | Low | "Descend via" has been misunderstood by pilots and controllers. New changes to the Controller's Handbook (7110.65R)[7] and the Aeronautical Information Manual[8] clarify "descend via" and "expect". They specify that controllers should add runway number when STAR assigned by TRACON. Pilots cannot be given "descend via" when procedure includes "expect" altitude crossing restrictions. These changes are expected to resolve the issue. |
| 27 | Technical Interchange Meeting | | Southwest Airlines | ATC Procedures | | | High | Ambiguity in phraseology while flying RNAV SID and STAR procedures. RNAV seems to need more precise phraseology. |
| 28 | Pilot Deviations Report | | NASDAC | ATC Procedures | | | Low | Assigned procedure, SUNST ONE, flown but instructed to "descend via" arrival except maintain 13000.PIC acknowledged but descended below 13K' w/o clearance. PIC interpreted "descend via" to mean that he had to make the next hard altitude. Changes to 7110.65R[7] and the AIM[8] are expected to resolve this issue. |
| 29 | CHECKER 5 report | | FAA | ATC Procedures | | | Medium | Controller awareness issue related to route changes too close to common waypoint between STARs and transitions for /E/F/G/R. Recently implemented controller awareness training is expected to resolve this issue. |
| 30 | RNAV Task Force | FAA | FAA | ATC Procedures | | | Medium | FAA moving away from using "expect" in clearance because pilots aren't sure how to use the information (it shouldn't be treated as a clearance). |
| 31 | ASRS Review | | NASDAC | ATC Procedures | | | Medium | Frequent changes to arrival routes and runway for landing (LAX, LAS, PHX). ATC training has been implemented to provide controller awareness of pilot impact due to runway and route changes. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 32 | Technical Interchange Meeting | Tom Petrakis | LAS TRACON | ATC Procedures | | | High | No standard phraseology currently exists for climb clearances on SIDs where pilot should follow published restrictions ("descend via" is defined in controller's handbook). Different controllers will use different phraseology and pilots will often clarify whether they should comply with restrictions. FAA is undergoing final evaluation and testing for "climb via". |
| 33 | RAT # AMT01.2 | Terry Stubblefield | FAA | ATC Procedures | | | Medium | Non-standard reporting procedures required by ATC to compensate for ATC equipment automation deficiencies (e.g. pilots IDing type of SID being performed.) |
| 34 | RNAV Task Force | Jeff Williams | FAA | ATC Procedures | | | Medium | Pilots have neglected to re-program FMS after runway change. 7110.65R changes dictate that controller should give runway assignment on initial contact or as soon as possible when assigning a STAR with multiple runway transitions.[7] If a runway change occurs prior to 10 NM from runway transition point that the controller should provide vectors. These changes are expected to address the issue. |
| 35 | RAT # AMT01.1 | Terry Stubblefield | FAA | ATC Procedures | | | Medium | Potential conflict of Preferred Departure Rtes, Preferred Arrival Rtes and/or Preferred Departure Arrival Rtes from adjoining centers (e.g., MAHEM filed, but Salt Lake Center cleared via the BRUSR One Arrival) |
| 36 | RAT Issue Paper # TRN02.1.2 | Bruce Tarbert | FAA | ATC Procedures | | | Medium | Procedures need to be developed for vectoring aircraft on and off STARS to approaches to land. |
| 37 | RNAV Task Force | Jeff Williams | FAA | ATC Procedures | | | High | ATIS information should not be interpreted as being a clearance (with respect to assigned runway). Nevertheless, ATIS has been one means under discussion for providing likely runway information to flight crews. Many are concerned that ATIS is not an effective means to provide this information. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 38 | RNAV Task Force | Jeff Williams | FAA | ATC Procedures | | | Low | Relative to "descend via", new 7110.65R language provides clarification when a pilot is cleared to a fix that doesn't have a published altitude restriction.[7] (The change addresses the question, “What is the assigned altitude?”) This change is expected to resolve the problem. |
| 39 | RAT I #PDV01.4/RAT #AMT01.1 | Bruce Tarbert | FAA | ATC Procedures | | | Medium | Controllers sometimes have trouble with mix of RNAV and non-RNAV aircraft when assigning headings, courses (possible impact on separation). On simultaneous departure operations, controllers experience difficulties determining the correct heading to assign to non-RNAV aircraft to ensure that the required heading/course divergence is met (i.e., one aircraft is RNAV; one is not); impacts on controller ability to identify when separation is lost and pilot ability to respond to the potential loss of separation. |
| 40 | RNAV Task Force | John Timmerman | | ATC Procedures | DME/DME | Q Routes | Medium | Will controllers monitor DME performance in areas where there are critical DMEs? |
| 41 | RNAV Task Force | John Timmerman | | ATC Procedures | Equipment Capabilities | Q Routes | Medium | What are the controller expectations of turn anticipation? Controllers might be unable to predict profiles of RNAV-flown turns, possibly making it more difficult to integrate RNAV into traffic flow. |
| 42 | PARC Human Factors WG | Don Porter | FAA | ATC Procedures | Flight Crew Procedures | | High | During discussion on how to best provide crews with anticipated runway information to improve accuracy of FMS-loaded runway, Don expressed concern that this information not be put in ATIS because it's too long and pilots might not catch it. ATL and DFW airports currently addressing this issue by having controllers ask pilots to verify their programmed route. Due to ATC workload considerations, alternative solutions are being discussed. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
|---|---|---|---|---|---|---|---|---|
| 43 | RAT # AMT02.1 | Bruce Tarbert | FAA | ATC Procedures | Flight Plan Suffix | | Medium | ATC automation automatically assigns STARS based on suffix rather than on actual filed FP: Pilot unprepared, increased workload, communications; Increased controller workload. |
| 44 | RAT Issue Paper # TRN02.1.2 | | FAA | ATC Procedures | FMS (other) | | Medium | Issuance of interim altitudes affects the FMS ability to fly the vertical path and meet constraints. It's easier for flight crews to stay on VNAV during arrivals. ATC training has addressed this issue. |
| 45 | RNAV Task Force | Jeff Formosa, Al Herndon | MITRE | ATC Procedures | FMS Offsets | | Low | Lost comm and re-join procedures should be defined when FMS offsets are used by ATC. Path performance may not be predictable due to variance between FMS models (intercepting, turn angles). Different FMS models may handle offsets differently. |
| 46 | PARC Human Factors WG | Don Porter | FAA | ATC Procedures | Procedure Design | | High | An issue exists concerning the most effective way to indicate the top altitude to pilots during an RNAV SID. In a study, pilots responded much better to a "climb via" clearance that included a top altitude when compared to one where the top altitude was printed on the chart. (Pilots may not have been conditioned to look for a top altitude on the chart because it's not in a consistent location and it may be lost in the clutter.) |
| 47 | ASRS Review | Richard Barhydt | NASA | ATC Procedures | RNAV SID/STAR | | Medium | Traffic conflicts may be caused by interactions between RNAV and conventional procedures. |
| 48 | ASRS Review | Richard Barhydt | NASA | ATC Procedures | RNAV SID/STAR | | High | Assigned altitude is sometimes ambiguous when aircraft is operating off of published route. (Controllers should provide an assigned altitude when providing radar vectors). |
| 49 | ASRS Review | Richard Barhydt | NASA | ATC Procedures | RNAV SID/STAR | | Medium | Different controllers use inconsistent terminology to provide the same clearance (e.g. "descend via" and "comply with restrictions").. Changes to 7110.65R[7] have clarified this issue. |

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| 50 | RNAV Task Force | Steve Ferra | FAA Tech Center | ATC Procedures | RNAV SID/STAR | | High | Initial studies have been conducted to investigate use of "climb via" phraseology (comparable to "descend via"). How should the top altitude be depicted? Should it be provided on all SIDs? |
| 51 | ASRS Review | Richard Barhydt | NASA | ATC Procedures | RNAV SID/STAR | | Low | Omission of word "RNAV" when assigning an RNAV SID/STAR has caused pilot confusion. |
| 52 | RNAV Task Force | Don Porter | FAA | ATC Procedures | RNAV SID/STAR | | High | Potential confusion related to phraseology associated with "climb with restrictions" and "maintain". FAA is undergoing final evaluation and testing for "climb via". |
| 53 | ASRS Review | Richard Barhydt | NASA | ATC Procedures | RNAV SID/STAR | | Medium | Some aircraft have been cleared to a fix that isn't depicted on the chart. |
| 54 | RNAV Task Force | Cathy Adams | NASA | ATC Procedures | RNAV SID/STAR | | Low | Radio calls initially increased on some RNAV SID/STAR procedures due to pilot clarification of controller intentions. A MITRE study has shown a reduction in air/ground communications across different facilities. |
| 55 | Technical Interchange Meeting | John Anderson | Continental Airlines | ATC Procedures | RNAV SID/STAR | Flight Crew Procedures | Medium | Clearances that require pilot to take aircraft off VNAV path (speed restrictions different from those published or intermediate level-offs) can prevent the aircraft from meeting downstream restrictions. Keeping aircraft on VNAV path considered to be optimal. What situations may prevent ATC from keeping an aircraft on VNAV? Are there other alternatives? ATC training has emphasized that controllers should try to keep aircraft on the RNAV path. |
| 56 | Technical Interchange Meeting | John Anderson | Continental Airlines | ATC Procedures | RNAV SID/STAR | Flight Crew Procedures | Medium | Last minute runway or route changes while on RNAV SID/STAR can lead to programming errors and high crew workload. Each runway has its own transition and pilots need to clean up discontinuity. ATC training has raised awareness of this issue. |

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| 57 | PARC Human Factors WG | PARC Human Factors WG | PARC Human Factors WG | ATC Procedures | RNP Approaches | | High | Study determined that shallow blunders (15 deg track deviation) took longer for controllers to identify (distinguish from standard track errors) than larger blunders. What procedures, training, or decision support systems are needed to help controllers perform this task? |
| 58 | Technical Interchange Meeting | John Anderson | Continental Airlines | Chart/Database Commonality | | | Medium | Navigation database and chart update cycles differ by two weeks. This difference can cause pilots to use charts that have some non-current data if they miss the chart effective date. |
| 59 | RNAV Task Force | Jim Terpstra | Jeppesen | Chart/Database Commonality | | | High | Charted waypoints should be consistent with FMS Nav Database. |
| 60 | RNAV Task Force | Jim Terpstra | Jeppesen | Chart/Database Commonality | | | High | Jeppesen postponing implementation of new ARINC 424 coding that allows more than one same-type approach at the same runway. Some FMSs are not able to accommodate the change. In these cases, the pilot may not be aware of the approach he's getting when it's selected. Criteria are needed to determine the default (primary) approach. |
| 61 | RNAV Task Force | Bill Royce | Boeing | Chart/Database Commonality | Charting | | Low | Non ILS charts should be updated to ensure they reflect VNAV descent angle that's in navigation database (when available). This action has been accomplished in the U.S. |
| 62 | RNAV Task Force | Jim Terpstra | Jeppesen | Chart/Database Commonality | Charting | FMS Nav Database | High | Some differences exist between chart and Legs page for DME fixes (former shows DME distance and latter represents it as waypoint name). |
| 63 | RNAV Task Force | Jim Terpstra | Jeppesen | Chart/Database Commonality | Equipment Capabilities | | High | Pilots should pay extra attention to tracking performance when using FMS for non-RNAV SID/STARs. |

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| 64 | RNAV Task Force | Sam Miller | Boeing | Chart/Database Commonality | FMS Nav Database | Airline Procedures | Medium | Flight crews have reported discrepancies between track to on FMS Legs page and that published on approach chart. Discrepancy is due to different update cycles between FMS and approach plates and is not considered to be a problem. Training material could make pilots aware of this issue. |
| 65 | RNAV Task Force | | Intl Chart and Database Harmonization WG | Chart/Database Commonality | FMS Nav Database | Charting | Medium | Inconsistency exists between FMS and charts concerning whether direction (N,S,E,W) is placed before or after coordinates. This issue results in entry errors and can impact ATC communications. Standards are needed for acceptable differences between charts and databases in areas including magnetic variation, mileage, and procedure title). Confusion can result if FMC computed information differs from chart or navigation database. |
| 66 | NASA FAA Chart Review | Richard Barhydt | NASA | Charting | | | Low | Apparent inconsistencies sometimes exist between depicted route and textual description. This issue appears to be a rare situation. |
| 67 | NASA Chart Review | Richard Barhydt | NASA | Charting | | | Low | At least one chart (Chezz RNAV 2 SID, PHX) has same notes depicted in two different locations on chart. |
| 68 | KCLT-Checker 5 SID;RAT# PDV01.2 | Terry Stubblefield/ Bruce Tarbert | FAA | Charting | | | High | Chart clutter causes extensive search time, workload and procedure confusion. |
| 69 | KCLT-Checker 5 SID;RAT# PDV01.2 | Terry Stubblefield/ Bruce Tarbert | FAA | Charting | | | High | Chart clutter makes reading during turbulence or at night difficult. |
| 70 | KCLT-Checker 5 SID;RAT# PDV01.2 | Terry Stubblefield/ Bruce Tarbert | FAA | Charting | | | High | Collocation of information should be carefully examined for both primary chart elements and notes. |
| 71 | KCLT-Checker 5 SID;RAT# PDV01.2 | Terry Stubblefield/ Bruce Tarbert | FAA | Charting | | | High | Collocation of information should be carefully examined: Too much information interferes with readability. Revise format or location to optimize chart real estate. |

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| 72 | NASA FAA Chart Review | Richard Barhydt | NASA | Charting | | | Medium | Different symbology/wording is sometimes used to indicate the same thing (altitude crossing restrictions indicated by bar above/below altitude on some charts and "cross at" on others). These differences may be due to a format change after a particular chart cycle. |
| 73 | RNAV Task Force | Frank Alexander | Northwest Airlines | Charting | | | Medium | Discussion underway to consider graphical depiction of some flight tracks based on leg type. Would this information add value? |
| 74 | RNAV Task Force | Jim Terpstra | Jeppesen | Charting | | | Medium | SID/STAR textual description should clarify whether waypoint is fly-by or fly-over. |
| 75 | Technical Interchange Meeting | | Southwest Airlines | Charting | | | Medium | Frequencies for VOR that are used to define the geometry of the procedure should be on charts for verification. |
| 76 | RNAV Task Force | Bill Vaughn, Kathy Abbott | Continental Airlines, FAA | Charting | | | High | ‘NA' on LNAV/VNAV minima line is confusing. Some pilots have interpreted it to mean they can't use VNAV on the approach. VNAV can be used on the approach and the 'NA' refers to 'not applicable’ or ‘not available.' A different format is likely needed. |
| 77 | TAOARC Issue Paper | Kathy Abbott | FAA | Charting | | | Medium | Naming minima lines on approach plates the same as an operational mode could cause confusion/inappropriate operating assumptions. |
| 78 | ASRS Review | Cathy Adams | ASRS | Charting | | | Medium | Pilots confused over descent path/gradient labeling. Would like percent or feet/nm. |
| 79 | NASA Chart Review | Richard Barhydt | NASA | Charting | | | High | Placing the notes, text description, and obstacle information on the chart can lead to high chart clutter |
| 80 | Technical Interchange Meeting | Terry Stubblefield | FAA | Charting | | | High | Procedure should not bear same name as any waypoint: BRUSR ONE ARRIVAL, MAHEM STAR, etc. |

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| 81 | TAOARC Issue Paper | Terry Stubblefield | FAA | Charting | | | High | Minima lines are operationally dependent rather than sensor dependent. It is not clear if the problem is sensor vs. operational capability. In some cases, there may be a problem with pilots thinking they can use minima their aircraft is not capable of handling. |
| 82 | NASA Chart Review | Richard Barhydt | NASA | Charting | | | Medium | On some charts, there's nothing visually compelling to distinguish "at or below" from "at or above" restrictions. Will pilots be able to recognize the difference on a quick glance? |
| 83 | NASA Chart Review | Richard Barhydt | NASA | Charting | | | Medium | When chart has too much information to place textual altitude restriction information next to waypoint, the information is placed elsewhere on the chart. The location of this cross-referenced information appears to be chart specific and is not standardized. Under adverse conditions, will pilots be able to quickly reference it? |
| 84 | RNAV Task Force | Bill Royce | Boeing | Charting | DME/DME | | Low | "DME/DME RNP 0.3 NA" note on many charts is unnecessary because this capability can be demonstrated on a case by case basis. |
| 85 | RNAV Task Force | Bill Royce | Boeing | Charting | Equipment Capabilities | | Medium | "ADF Required" note on charts is confusing for operators with equivalent capability. |
| 86 | PARC Human Factors WG | | PARC Human Factors WG | Charting | Flight Crew Procedures | | High | Group discussed possibility of "SID Ops" page that would cover general RNAV SID issues and any specific issues for RNAV procedures at a particular airport (would be placed at beginning of approach charts for a particular airport). Would this approach be an effective way to disseminate RNAV SID information? |

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| 87 | RNAV Task Force | RNAV Task Force | RNAV Task Force | Charting | Flight Crew Procedures | | Medium | RNAV Task Force recommends that minimum temperature be published for each instrument approach procedure. Operations below this minimum temperature could be conducted by VNAV aircraft that can apply appropriate temperature corrections and can compute a straight line geometric path or use an approved FMS vertical path angle function. |
| 88 | RNAV Task Force | Bill Royce | Boeing | Charting | Procedure Design | | High | Blank minima line under "LNAV/VNAV" leads some crews to believe that it's not authorized. |
| 89 | NASA Chart Review | Richard Barhydt | NASA | Charting | Procedure Design | | High | Chart complexity is sometimes increased for little apparent operational value (e.g. one chart depicts 4 different altitudes in close proximity for altitude conditional waypoints that are within 20 ft of a rounded altitude: 1080 ft and 1120 ft) |
| 90 | KCLT-Checker 5 SID;RAT# PDV01.2 | Terry Stubblefield/ Bruce Tarbert | FAA | Charting | Procedure Design | | Low | Confusion over conditional altitude restrictions based on landing runway (multiple restrictions listed over single fix). Changes to Order 7100.9D discourage this practice. |
| 91 | PARC Human Factors WG | Kathy Abbott | FAA | Charting | Procedure Design | | Medium | Pilots are sometimes confused when the published top altitude is lower than a charted altitude restriction (e.g. at or above FL250 restriction at BIKKR on LAS RNAV SID). The reason for the restriction is not clear to the pilot and the chart is internally inconsistent. In this case, the restriction is needed for DME/DME. |
| 92 | NASA Chart Review | Richard Barhydt | NASA | Charting | Procedure Design | | High | Some charts are cluttered and it's difficult to quickly associate an intersection with its crossing restrictions. |
| 93 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | Charting | Procedure Design | | High | Use of 'LNAV/VNAV' minima line may be confusing to pilots because these terms are already used as autoflight modes. |
| 94 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | Charting | Procedure Design | | High | Use of 'NA' in LNAV/VNAV minima line despite charted glide path angle inside final approach fix (implies that procedure cannot be flown as depicted). |

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| 95 | Technical Interchange Meeting | John Anderson | Continental Airlines | Charting | RNAV SID/STAR | | Medium | Extremely small text on charts is difficult to read. |
| 96 | RNAV Task Force | RNAV Task Force | RNAV Task Force | Charting | RNAV SID/STAR | | Medium | Some pilots interpreting "Aircraft departing north ..." on ATL RNAV SID to mean the direction of their ultimate destination. It's intended to mean the takeoff direction. New wording may be needed. |
| 97 | Technical Interchange Meeting | John Anderson | Continental Airlines | Charting | RNAV SID/STAR | | High | There should be a review of requirements related to information that must be printed on a chart. Information like obstacle notes increases clutter and often adds no operational value. |
| 98 | FAA RNP KSN site | Terry Stubblefield | FAA | Charting | RNP Approaches | | High | Charting for RNP approaches should depict information in order pilots needs it, be consistent, have minimum clutter, be readable, and support planning. (Potential issue: how will procedure designers be able to incorporate these desirable attributes?) |
| 99 | PARC Human Factors WG | Terry Stubblefield | FAA | Collaboration | | | High | Different parts of FAA contribute separately to different procedure areas and don't necessarily talk to each other. This lack of communication can lead to chart inconsistencies, such as between the textual description and visual depiction. |
| 100 | RNAV Task Force | Ted Demosthenes | ICAO Operations Panel | Collaboration | | | High | Numerous organizations around the world are looking into performance-based navigation issues (FAA/JAA, FAA/Industry, ICAO, etc.) Collaboration is needed to ensure consistent findings and to avoid duplication of efforts. Prioritization of issues is required to ensure that most important ones are addressed first and to conserve valuable resources. |

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| 101 | RAT #NAV 02.4.3 | AFS 410/AIR130 | FAA | Equipment Capabilities | | | Low | Aircraft may be equipped with AHRS, but not INS or IRS. Operators equipped with aircraft having AHRS and DME/DME positioning sometimes take /F credit (FMS capability) erroneously. Because position not calculated by multiple nav sensors (DMEDME,GPS,VOR/DME or IRS), the accuracy is suspect. Performance issues relate to drift, credit for capability, performance after takeoff, and radio updating: Fifteen degrees course divergence has been reported. Operator must take responsibility for properly reporting equipment capabilities. AC 90-100 provides guidance in these areas.[5] |
| 102 | RNAV Task Force | Operations Panel | ICAO | Equipment Capabilities | | | High | Concerns have been raised regarding the use of continuous descent approaches without vertical path guidance. |
| 103 | RNAV Task Force | Cathy Adams | NASA | Equipment Capabilities | | | Medium | DME counts down and FMS counts up leading to potential confusion. |
| 104 | RAT # NAV 02.5.1 | | FAA | Equipment Capabilities | | | Medium | FMS might not acknowledge presence or absence of facility's identifier. |
| 105 | RAT # NAV 02.5.1 | | FAA | Equipment Capabilities | | | Low | FMS might not acknowledge VOR service volume limitations in areas where error is 6.5 degrees. VOR/DME updating is uncommon for FMS. |
| 106 | Bluecoat Report 28 May 2003 | | Bluecoat | Equipment Capabilities | | | Medium | Map shift noticed on taxi-out: Manufacturer indicated that ground-based updates do not occur below 100 kts. |

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| 107 | RAT # NAV 02.4.2 | | FAA | Equipment Capabilities | | | High | Different multi-sensor avionics have different weightings or source priorities for nav sources (DME &/or IRU/S) depending on phase of flight and the navaid environment. Differences include: number of facilities searched (several DMEs vs. only 2);strength of station; monitoring and identification of facility status (active or down);within a 30-150 degree range of a/c nose; some can inhibit facilities "off air"-others cannot. Implications for position integrity for RNP to .3, FAA responsibility to confirm nav data integrity through flight inspection (includes confirmation of DME signals along IAP.) |
| 108 | RAT # NAV 02.4.2 | | FAA | Equipment Capabilities | | | Low | Suffix /E and /F: nav signal source priority differs among non-standardized avionics |
| 109 | RNAV/SID STAR Implementations | | FAA | Equipment Capabilities | | | High | Suffix E-G,R boxes do not function the same. Need to ID differences and where they cannot meet TERPS criteria. |
| 110 | RNAV Task Force | Frank Alexander | Northwest Airlines | Equipment Capabilities | | | Medium | What should be the minimum equipment standards for conducting various RNAV operations? AC 90-100 now provides guidance in this area.[5] |
| 111 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | Equipment Capabilities | | | Medium | Inability of pilots to verify nav info for GPS only procedures when they cannot crosscheck against raw nav info. |
| 112 | AC 90-100 | | FAA | Equipment Capabilities | Alerting | | High | Aircraft systems must allow pilots to adequately monitor their performance. What are some of the important design and alerting issues? |

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| 113 | RNAV Task Force | Bricknell | | Equipment Capabilities | Alerting | DME/DME | High | Several critical DMEs have been identified for Q routes. Inertial system required to coast through DME coverage gaps. Is there an issue related to how crew identifies a lost critical DME? What are the backup procedures? |
| 114 | RAT #PDV03.3 | | FAA | Equipment Capabilities | Alerting | RNAV Approaches | Medium | What are the appropriate alerting features for non-GPS sensor failures (especially on RNAV approaches)? |
| 115 | RAT #NAV02.3 | | FAA | Equipment Capabilities | Alerting | RNP Approaches | Medium | Alerting limits for RNP navigation on instrument procedures are based on containment area but not obstacle clearance. When available, RNP alerts are triggered by exceeding manual RNP settings, database-coded RNP value by leg (some systems), default RNP value (derived from phase of flight), and/or the FTE assumptions from RTCA DO-208. Is there a delay or dwell built into alerts to allow for corrections? |
| 116 | FAA RNP KSN site | Terry Stubblefield | FAA | Equipment Capabilities | Alerting | RNP Approaches | High | Containment alerting should consider human factors principles. Potential design issues include type of alert (visual/aural), color, intensity, flash/steady state, location in scan. |
| 117 | RNAV Task Force | Dave Nakamura | Boeing | Equipment Capabilities | Alerting | RNP Approaches | Medium | RNP MASPS doesn't currently define alarm threshold for vertical RNP. How should this standard be developed? AC 90-101 now provides guidance in this area.[17] |
| 118 | Technical Interchange Meeting | Richard Barhydt | NASA | Equipment Capabilities | Alerting | RNP Approaches | High | Some aircraft don’t provide alerts when an aircraft’s position exceeds RNP. (RNP alerts are limited to cases where EPU exceeds RNP and do not account for FTE.) Are current position monitoring aids on these aircraft sufficient? Are different requirements needed for different levels of RNP? |

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| 119 | RNAV Action Team AMT01.1 | | FAA | Equipment Capabilities | ATC Procedures | | Medium | It's helpful for controllers to be able to distinguish between aircraft flying a conventional procedure and an RNAV procedure. Controller awareness of RNAV/non-RNAV procedure status during simultaneous operations may help reduce traffic conflicts. Potential ground automation changes include site-adaptable symbol in full data block to distinguish aircraft assigned RNAV, suggesting a prefix preceding a/c ID; toggle RSI ("RNAV Status indicator") on/off when a/c assigned or taken off RNAV procedure by a controller; and use of 2nd scratch pad to display RNAV data with initial contents controlled by fix pair adaptation. |
| 120 | PARC | Jeff Williams, John McGraw | FAA | Equipment Capabilities | Autopilot | RNP Approaches | High | Uncertain tracking performance may occur during TOGA (takeoff-go around mode) and possibly lead to unexpected aircraft behavior. This problem appears to be more of an issue for older aircraft. |
| 121 | AC 90-100 | | FAA | Equipment Capabilities | Charting | | High | Pilots must verify the proper onboard equipage exists to perform desired procedures. Are the equipment requirements understandable? |
| 122 | RAT | | FAA | Equipment Capabilities | DME/DME | | Medium | Service volume saturation for DME should be examined. |
| 123 | RNAV Task Force | Bill Vaughn, Kathy Abbott | Continental Airlines, FAA | Equipment Capabilities | DME/DME | Alerting | High | When is a DME/DME aircraft allowed to fly an RNAV SID, STAR, or approach? How are pilots alerted in case of a DME failure? Can the aircraft revert to VOR/DME? |
| 124 | SAE G10 | Cathy Adams | NASA | Equipment Capabilities | EFB | | High | Discussion on pilot's ability to access and interpret information from the EFB when compared to use of paper charts. |
| 125 | EFB report | Divya Chandra | VOLPE | Equipment Capabilities | EFB | | High | Display of EFB procedure data and annunciation of conditions to pilot may not be easily accessible. |

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| 126 | EFB report | Divya Chandra | VOLPE | Equipment Capabilities | EFB | | High | Visual perception and performance impacts of instrument procedures depicted on EFB: accessing procedure, operating EFB to see/understand procedure depicted. |
| 127 | ASRS Review | Richard Barhydt | NASA | Equipment Capabilities | EFIS | RNAV SID/STAR | High | Lack of map display can lead to high workload and possible errors when flying RNAV departure and arrival procedures. Should there be a requirement to have a map display? |
| 128 | Technical Interchange Meeting | Sam Miller | Boeing | Equipment Capabilities | EFIS | RNP Approaches | Medium | B-737 shows missed approach path in cyan to distinguish it from active path. The missed approach path turns magenta if activated. (Potential issue - do pilots have trouble distinguishing approach from missed approach path when both are shown in magenta?) |
| 129 | Pilot Deviations Report | | NASDAC | Equipment Capabilities | FMS (other) | | High | Aircraft departed DOOLY1 RNAV at ATL but did not adequately maintain track (1.5 mi off course); pilot said Nav Display indicated on course. Deviation to be investigated. |
| 130 | RNAV Task Force | Operations Panel | ICAO | Equipment Capabilities | FMS (other) | | High | Differences exist in FMS performance. Recommendation made that procedure flyability should be assessed before publication. |
| 131 | RNAV Task Force | Mike DeJonge | Smiths Industries | Equipment Capabilities | FMS (other) | | High | Different FMSs will construct path differently for large angle turns at a waypoint (some will overshoot outbound course, then re-intercept). These differences may lead to path tracking inconsistencies. |
| 132 | RNAV Task Force | Randal Ottobre, John O'Neill, Al Herndon | MITRE | Equipment Capabilities | FMS (other) | | High | FMS design differences lead to inconsistent path tracking performance. These differences may be unanticipated by controllers. |
| 133 | RAT #PDV01.3 | | FAA | Equipment Capabilities | FMS (other) | | Medium | Waypoints: Trajectory representation of fly-by and fly-over waypoints differs between aircraft models (Boeing vs. Airbus) |

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| 134 | RAeS Flight Operations Group | Kathy Abbott | FAA | Equipment Capabilities | FMS (other) | Airline Procedures | Medium | On Airbus aircraft, when an approach transition ("Approach Via") shares a common fix with a programmed STAR, the FMGC will default to the "Approach Via" and delete all remaining STAR waypoints after the common fix. The resulting path may lead to confusion or a potential path deviation. |
| 135 | RAeS Flight Operations Group | Kathy Abbott | FAA | Equipment Capabilities | FMS (other) | Airline Procedures | Medium | On Boeing aircraft, pilots should use the FMS Legs Page (rather than the Route Page) when clearing discontinuities to prevent unintentional waypoint deletion. |
| 136 | RAeS Flight Operations Group | Kathy Abbott | FAA | Equipment Capabilities | FMS (other) | Airline Procedures | Medium | On Boeing aircraft, the FMS Route Page does not necessarily show all waypoints along the route. Pilots should use the Legs Page to verify that all desired waypoints are part of the active route. |
| 137 | PARC Human Factors WG | Sam Miller | Boeing | Equipment Capabilities | FMS (other) | Airline Procedures | Medium | Changing runway on FMC performance page doesn't automatically update the route (converse occurs - change to runway on route does change it on performance page). Flight crews should be trained on this nuance. |
| 138 | ASRS Review | Richard Barhydt | NASA | Equipment Capabilities | FMS (other) | Airline Procedures | High | Unexpected FMS mode transitions have caused altitude deviations on RNAV SIDs and STARs. This issue may warrant additional training (specific issue noted for Airbus aircraft). |
| 139 | PARC | Jeff Williams, John McGraw | FAA | Equipment Capabilities | FMS (other) | ATC Procedures | High | Dispersion of flight tracks during turn segments leads to unpredictable tracking performance and higher controller workload. |
| 140 | RNAV Task Force | Kathy Abbott/ Tom Imrich | FAA/Boeing | Equipment Capabilities | FMS (other) | EFIS | High | FMS interfaces on some regional and business jets do not clearly convey the loaded runway and provide error messages that are not fully understood. |

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| 141 | PARC | Bill Vaughn | Continental Airlines | Equipment Capabilities | FMS (other) | RNAV Approaches | High | FMS requirements are needed to identify RNAV Phase II/III performance criteria. Potential human factors issues include minimum RNAV/RNP performance capabilities, operations issues related to flight director, autopilot, engagement altitudes, and operational mitigations. |
| 142 | FAA Designee Newsletter | Terry Stubblefield | FAA | Equipment Capabilities | FMS (other) | RNAV Approaches | High | VNAV on some GPS equipment not certified for VNAV approaches but can function at appropriate descent rate. Function may not reflect required glidepath based on obstacles. Pilots should know limitations. |
| 143 | RNAV Task Force | unknown source | | Equipment Capabilities | FMS (other) | RNAV Approaches | High | Computed glide path angles may take aircraft below step-down altitudes. |
| 144 | PARC Human Factors WG | | PARC Human Factors WG | Equipment Capabilities | FMS (other) | RNAV SID/STAR | Medium | One FMS type disregards speed restriction after sequencing a waypoint. This design feature may impact lateral tracking performance in a turn. |
| 145 | PARC | Pedro Rivas | | Equipment Capabilities | FMS (other) | RNP Approaches | High | How should the FMS transition between segments of different width? |
| 146 | RAT #NAV02.1 | AFS-410/AIR130 | FAA | Equipment Capabilities | FMS Nav Database | FMS (other) | Medium | Criteria need to be established to define "advanced RNAV" performance capabilities. AC 90-100 now provides guidance in this area.[5] |
| 147 | RAT #NAV02.4.1.3 | AFS-410 | FAA | Equipment Capabilities | FMS Nav Database | Inertial | Medium | QA waypoints designed to mitigate INS drift may require monitoring. Proximity to DER is a potential issue. |
| 148 | (Source: RAT Issue Paper #NAV 02.4.1; Checker 5 SID at CLT; SIDs at LAS) | | FAA | Equipment Capabilities | Inertial | | High | Impact of loss of radio updating on operations. Concern over the ability of INS to meet minimum navigation performance standards to execute the procedures. |
| 149 | PARC | Frank Alexander | Northwest Airlines | Equipment Capabilities | Inertial | | Medium | Inertial Reference Unit (IRU) performance requirements to be addressed for initial segments of RNAV/RNP procedures. IRU alignment procedures will also be addressed. |

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| 150 | CHECKER 5 report | | FAA | Equipment Capabilities | Inertial | | Medium | Map shift due to failure to update IRS prior to takeoff may cause SID path deviations due to radio source updating once airborne. |
| 151 | RAT #NAV02.4.1.2 | AIR 130 | FAA | Equipment Capabilities | Inertial | | High | Not known if an INS system can support navigation on an RNAV SID while in inertial coasting state after takeoff. INS may not meet nav performance expectations. TERPS criteria and these nav performance standards are not aligned, leading to a potential misunderstanding as to whether or not aircraft meet performance expectations for procedure. |
| 152 | RNAV Task Force | Barry Miller | FAA | Equipment Capabilities | RNAV Approaches | Flight Crew Procedures | High | When conducting an approach with Baro VNAV, pilots must know their aircraft's VNAV capabilities and avoid descending below the step-down altitude. (Is it workload intensive for flight crews to do this monitoring?) |
| 153 | RNAV Task Force | Randal Ottobre, John O'Neill, Al Herndon | MITRE | Equipment Capabilities | RNAV SID/STAR | | Medium | One FMS type doesn't support speed only constraints. Pilot must perform work-around solution for some procedures. |
| 154 | RNAV Task Force | Dave Nakamura | Boeing | Equipment Capabilities | RNP Approaches | | High | Can RNP apply only to GNSS equipped aircraft? |
| 155 | Technical Interchange Meeting | Sam Miller | Boeing | Equipment Capabilities | RNP Approaches | Alerting | High | Navigation performance scales give valuable trend information on estimate of position uncertainty (EPU). This information can be used by pilots for rapid indication of sensor performance. (Potential issue - can pilots who don't have these scales maintain the same level of situation awareness during a degrading situation?) |
| 156 | RNAV Task Force | Bill Royce | Boeing | Flight Crew Procedures | | | Medium | Flight crew procedures should be better defined when conducting cold weather operations with temperature-limited chart. |
| 157 | Technical Interchange Meeting | Brian Townsend | Air Line Pilots Association | Flight Crew Procedures | | | Medium | On Airbus aircraft, pilots should verify that the MDCU displays the correct VIA on arrivals page. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
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| 158 | ASRS Review | Richard Barhydt | NASA | Flight Crew Procedures | Airline Procedures | RNAV SID/STAR | High | Some waypoint altitude restrictions have been busted while hand-flying. Concerns have been raised associated with hand flying procedures having a high number of flight segments and waypoint constraints. |
| 159 | PARC | Jeff Williams, John McGraw | FAA | Flight Crew Procedures | Equipment Capabilities | RNP Approaches | High | Flight crew must verify that smaller RNP is available prior to segment transition. |
| 160 | Technical Interchange Meeting | John Anderson | Continental Airlines | Flight Crew Procedures | FMS Nav Database | RNP Approaches | High | Current software normally requires pilots to enter new RNP value for every segment of approach. Would be easier to have RNP coded as part of procedure and change automatically with each segment. Capability is currently being developed. Potential workload issue for flight crews. |
| 161 | RNAV Task Force | Bill Vaughn, Kathy Abbott | Continental Airlines, FAA | Flight Crew Procedures | Inertial | | Low | When IRU is used for an RNAV SID, can a quick align be used in place of a full align? |
| 162 | MAHEM STAR implementation-KPHX | Terry Stubblefield | FAA | Flight Crew Procedures | Procedure Design | | Medium | Pilot selected wrong STAR. Capture errors have occurred when action sequence is relatively automated and several procedures share initial common elements. One example is where pilots expect a frequently issued arrival clearance but receive another. |
| 163 | MAHEM STAR report | | FAA | Flight Crew Procedures | RNAV Approaches | | High | Occasional difficulty maintaining VNAV path on RNAV approach and descending below step down alts. |
| 164 | MAHEM STAR report | | FAA | Flight Crew Procedures | RNAV Approaches | | Medium | Vertical profile: Difficulty mentally crosschecking computations during climb or descent. Descent profiles are difficult for pilots to crosscheck with angles, FPM, and raw data. |
| 165 | RNAV Task Force | Sam Miller | Boeing | Flight Crew Procedures | RNP Approaches | | Medium | Some concerns exist that AC 90-101[17] guidance for pilots to confirm the altimeter setting between the IAF and FAF may lead to high crew workload during that flight phase. |

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| 166 | Technical Interchange Meeting | | Naverus | Flight Crew Procedures | RNP Approaches | Airline Procedures | High | Flight crews should perform standard procedures for each RNP approach (e.g. LNAV/VNAV engagement, engine out procedures, checklists, approach call outs). Potential issue - how will airlines incorporate these recommendations into their training program? |
| 167 | MAHEM RNAV STAR Issues | | FAA | Flight Crew Procedures | Training | | Medium | Several cases reported where pilots expected a different transition. Pilots neglected to re-program FMS and flew wrong procedure. |
| 168 | ASRS Review | Richard Barhydt | NASA | Flight Crew Procedures | Training | Procedure Design | High | When running behind, some flight crews have failed to do adequate chart briefings prior to takeoff. These briefings are especially important for procedures that incorporate multiple flight paths, segments, and waypoint constraints. |
| 169 | RNAV Task Force | Vincent Chirasello | FAA | Flight Plan Suffix | | | High | Current flight plan suffixes do not adequately describe aircraft capabilities. Suffixes do not enable controllers to adequately assess flight crew/aircraft capabilities to perform various operations. A few examples: '/R' stands for RNP (but what level?) Who can fly a Q route? /E and /F aircraft with GPS aren't able to fly a GPS procedure. The U.S. doesn't harmonize flight plans with ICAO. Lack of capable suffix prevents ATC Host from helping to automate this process. |
| 170 | PARC Human Factors WG | Kathy Abbott | FAA | Flight Plan Suffix | | | High | Flight plan suffix should describe a capability, not a type of equipment. (Current suffixes do not meet these criteria.) |
| 171 | RAT #NAV02.2 | AFS-420/ATP501 | FAA | Flight Plan Suffix | | | High | Flight plan suffixes should be modified to better align with aircraft requirements and capability. |
| 172 | RNAV Task Force | Tom Imrich | Boeing | Flight Plan Suffix | | | High | Flight plan suffixes should adequately address an aircraft's CNS capabilities, while being easy to understand for pilots and controllers. |

| Issue (No) | Source (No) | Contact | Organization | Category | Keyword #1 | Keyword #2 | Priority H, M, L | Synopsis |
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| 173 | Pilot Deviations Report | | NASDAC | Flight Plan Suffix | ATC Procedures | | Medium | Foreign carrier assigned RNAV procedure flew off course and created a conflict. Carrier was not authorized to fly RNAV in US. Possible suffix problem. |
| 174 | AC 90-100 | FAA | FAA | Flight Plan Suffix | Flight Crew Procedures | Airline Procedures | High | Pilots are required to file the appropriate flight plan suffix. Are the suffixes adequate? Do pilots/dispatchers know what they are? |
| 175 | RNAV Task Force | John Timmerman | | Flight Plan Suffix | Q routes | ATC Procedures | Medium | How will controllers know whether aircraft are equipped to fly Q routes? (Only GNSS-equipped aircraft are allowed for Phase 1.) |
| 176 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | FMS Nav Database | | | Low | Courses and bearings might be different than published procedures. |
| 177 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | FMS Nav Database | | | High | Documented problems consist of:<br>Published procedures do not appear in the database;<br>Unpublished procedures may appear in the database;<br>Incorrect waypoint identification;<br>Waypoints are added to or deleted from published procedures;<br>Courses and bearings are different than published procedures;<br>Duplicate Identifiers are not all displayed<br>Instrument approach procedures are not displayed in the same manner as appears on the published material;<br>Some navaids are not in the database; and<br>“Hard” Altitudes cause violation of obstruction clearance criteria. |

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| 178 | RNAV Task Force | Jack Befus | Smiths Industries | FMS Nav Database | | | Medium | Errors in navigation databases can come from various sources. These errors can cause route discontinuities and path deviations. Procedures are needed to conduct integrity checks in critical areas. A more thorough analysis should be done to compare changes from the previous cycle. AC 20-153 now provides a process for ensuring navigation data integrity during the transition from source data to airline-specific files.[11] |
| 179 | RNAV Task Force | Jim Terpstra | Jeppesen | FMS Nav Database | | | Low | FMS can only store one holding pattern at a fix. Some approaches have different holding patterns at the same fix (corresponding to different approaches). Should holding patterns be part of a procedure? |
| 180 | Technical Interchange Meeting | AFS 410 | FAA | FMS Nav Database | | | Medium | MAGVAR may be different between collocated airport and navaid information. |
| 181 | RNAV Task Force | John Anderson, Kathy Abbott | Continental Airlines, FAA | FMS Nav Database | | | Medium | Map shifts are often the result of relocated navaids. Is this information being properly recorded in the nav database? |
| 182 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | | FMS Nav Database | | | Medium | National source data delivered to suppliers, encoded to vendor specific format (ARINC 424) is subsequently sold to FMS vendors utilizing in-house s/w for transforming the data to the display. Quality assurance related to data integrity could be improved as data are transformed from the national source point through to the FMS manufacturers. AC 20-153 now provides a process for ensuring navigation data integrity during the transition from source data to airline-specific files.[11] |

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| 183 | CHECKER 5 report | | FAA | FMS Nav Database | | | High | One FMS/GPS doesn't support runway transitions for STARS (ARINC rte type 3, 6, 9 & S) causing database provider to set up single procedure as several named procedures for each runway transition. Could cause capture error with pilots when selecting/loading correct procedure. This issue is an example of an FMS workaround that can lead to confusion and potential error. |
| 184 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | FMS Nav Database | | | Medium | Regular data upgrades impact software functioning. |
| 185 | RNAV Task Force | Jim Terpstra | Jeppesen | FMS Nav Database | | | Medium | Several navaid naming conventions can lead to flight crew confusion. Five letter VOR names can be confused with intersections of the same spelling. One approach in Barcelona uses the same name (but different identifier) for multiple fixes on the same approach. |
| 186 | RNAV Task Force | Jim Terpstra | Jeppesen | FMS Nav Database | | | High | Some DME stepdown fixes don't have waypoint names. |
| 187 | RNAV Task Force | Jim Terpstra | Jeppesen | FMS Nav Database | | | Medium | Some waypoint names correspond to multiple locations. Determining which one is being used can be confusing. |
| 188 | AFS-410 | | FAA | FMS Nav Database | | | Medium | Waypoints have been observed to drop off during arrival to LAS when procedure or runway changed. This issue appears to have occurred primarily during the introduction of RNAV SID/STAR procedures at LAS. |
| 189 | RAT Issue Paper # TRN02.1.2 | | FAA | FMS Nav Database | ATC Procedures | | High | After being assigned a new runway, the runway transition is sometimes not available in the FMS, requiring the flight crew to manually program the waypoints. This process leads to higher workload. |

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| 190 | LAX Report | | FAA | FMS Nav Database | ATC Procedures | | High | LAX Controller cleared aircraft to fix that was not in FMS. |
| 191 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | FMS Nav Database | Chart/Database Commonality | | High | Disparity between FMS/GPS-coded and published procedure: Data missing (wpts, transitions, altitudes) |
| 192 | RAT #NAV01.1 | Greg Tennille | MITRE | FMS Nav Database | Equipment Capabilities | Procedure Design | High | If FMS or GPS doesn't have functionality of leg type defined in procedure, database provider may use an alternative leg type which could lead to unanticipated flight path. Affects software update, hardware and ability of system to perform a required maneuver accurately. |
| 193 | Checker 5 Report | | FAA | FMS Nav Database | Procedure Design | | Medium | Canned database for engine out profile routings by location. Concern as to whether TERPS would consider these operations. |
| 194 | RNAV Task Force | Randal Ottobre, John O'Neill, Al Herndon | MITRE | FMS Nav Database | Procedure Design | | High | Database supplier misinterpreted procedure designer's intent resulting in path that wasn't checked for terrain and obstruction clearance. |
| 195 | ASRS Review | | NASA | FMS Nav Database | Procedure Design | | High | Descent gradient: FMS not able to replicate flight path as depicted on chart. Difference may cause computed path to fall below step-down altitudes. |
| 196 | ARINC 424 | Cathy Adams | NASA | FMS Nav Database | Procedure Design | | High | FMS navigation databases that don't support all path terminators in ARINC 424 can lead to workaround strategies that have undesirable consequences (such as path deviations). |
| 197 | RNAV Task Force | Jim Terpstra | Jeppesen | FMS Nav Database | Procedure Design | | Medium | Some conditional fixes can't be programmed into FMS (e.g. missed approach turn at waypoint or altitude, whichever is earlier). Conditional waypoints based on landing runway are another example. |

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| 198 | ASRS Review | Richard Barhydt | NASA | NOTAMs | | | Medium | Flight crew failed to notice NOTAM related to FMS data error. It's often difficult to extract important information from NOTAMs due to a large number of seemingly unimportant items. This issue may have additional considerations for RNP/RNAV. |
| 199 | PARC | Randy Kenagy, Ken Speir | AOPA, Delta Airlines | NOTAMs | | | Medium | NOTAM improvement is needed (currently too vague) when DoD degrades GPS signals in civilian airspace. |
| 200 | AC 90-100 | | FAA | NOTAMs | Flight Crew Procedures | Equipment Capabilities | Medium | Pilots must confirm availability of nav infrastructure during planned periods of use. Does adequate information exist to perform that task? Does it adversely affect pilot workload? |
| 201 | STAR Order 7100.9D | | FAA | Procedure Design | | | Medium | Excessive intercept angles can cause path interception problems. A 45 degree angle of intercept to a course is considered comfortable. |
| 202 | Checker 5 Report | | FAA | Procedure Design | | | Medium | Checker 5 procedure based on previous series of vectors into and out of airport. No task analysis done to determine impact on pilots while flying series of legs after prior operations converted to graphic depiction. The FAA has developed an 18-step process for implementing a new procedure. It addresses flyability and should mitigate the effects of this issue. |
| 203 | CHECKER 5 report | | FAA | Procedure Design | | | High | Determination made that Checker 5 procedure has excessive at or below/at or above restrictions in short succession |
| 204 | RNAV Task Force | | Obstacle Clearance Panel WG | Procedure Design | | | High | How should minima be adjusted for VNAV approaches to non-precision runways? |

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| 205 | *Aircraft On-Board Navigation Data Integrity: A Serious Problem*, Transport Canada Database Working Group Paper, 1997 | | Transport Canada | Procedure Design | | | High | Human performance (increase workload, reduced processing ability, tunneling, tracking) are attributed to certain procedure design features and overall complexity. The 18-step process for developing a new procedure should help address this issue. A comprehensive and specific set of design guidelines that concentrates on human performance still appears to be needed. |
| 206 | AFS-410, operational exp, implementation meeting notes; TIMs | Terry Stubblefield | FAA | Procedure Design | | | High | Impact of design on: meeting nav performance requirements. |
| 207 | AFS-410, operational exp, implementation meeting notes; TIMs | Terry Stubblefield | FAA | Procedure Design | | | High | Impact of design on situation awareness. The 18-step process for developing a new procedure should help address this issue. A comprehensive and specific set of design guidelines that concentrates on human performance still appears to be needed. |
| 208 | CHECKER 5 report | | FAA | Procedure Design | | | High | Reported that Checker 5 procedure doesn't fit/flow well with standard aircraft takeoff and departure profiles from the runway through 10,000 feet, through terminal arrival profiles, or through approach to landing profiles (aircraft configuration; interrupts normal cockpit workflows and procedures, etc.) The 18-step process for developing a new procedure should help address this issue. A comprehensive and specific set of design guidelines that concentrates on human performance still appears to be needed. |

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| 209 | RNAV Task Force | Operations Panel | ICAO | Procedure Design | | | High | Is it appropriate to use excessive climb gradients and other such techniques for purposes other than obstacle clearance (noise abatement, ATC flow management)? Concerns have been raised that flyability and flight crew workload is being affected for non-critical reasons. Guidelines are needed to ensure that procedure design provides proper balance between air traffic and operational needs. The 18-step process for developing a new procedure should help address this issue. A comprehensive and specific set of design guidelines that concentrates on human performance still appears to be needed. |
| 210 | Technical Interchange Meeting | | Southwest Airlines | Procedure Design | | | Medium | Pilots dislike minute course changes back and forth on STARs and SIDs. 1-3 degree changes are difficult to see/execute especially when FMS capabilities are limited. |
| 211 | ASRS Review | Richard Barhydt | NASA | Procedure Design | | | Medium | Some RNAV waypoints are difficult to pronounce and could lead to confusion if spoken over radio (e.g. PAIGW, EVXAF, TEYYI, etc.) FAA documentation addresses this issue. |
| 212 | ASRS Review | Richard Barhydt | NASA | Procedure Design | | | Medium | Two similar sounding fixes in close proximity has led to pilot confusion when they're spoken over the radio (e.g. BRAZI and Bradley). |
| 213 | RAT #PDV01.3 | | FAA | Procedure Design | | | High | Waypoints: Flyover/Flyby-Little guidance on how and when they should be used for procedure design. |
| 214 | CHECKER 5 report | | FAA | Procedure Design | | | High | Waypoints: proximity - procedure design guidelines should address waypoint proximity for effects on procedure complexity, pilot workload, and ability to meet constraints. |
| 215 | ASRS Review | Cathy Adams | NASA | Procedure Design | ATC Procedures | | High | Altitude and Speed restrictions: Procedure design and ATC management techniques might conflict. |
| 216 | ASRS Review | Cathy Adams | NASA | Procedure Design | ATC Procedures | | Medium | Approach too close to Military Operations Area (MOA) causes ATC to impose restrictions contrary to procedure. |

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| 217 | RNAV Task Force | | NASA | Procedure Design | ATC Procedures | | High | High intercept angles and close waypoints may increase workload, impose penalty on pilots ability to track flight path when taken off RNAV and asked to rejoin. |
| 218 | ASRS Review | Richard Barhydt | NASA | Procedure Design | ATC Procedures | Flight Crew Procedures | High | Pilot deviated around thundershowers and came in too high on fix to LAX. Are RNAV procedures sufficiently flexible to allow necessary tactical deviations for weather avoidance? |
| 219 | CHECKER 5 report | | FAA | Procedure Design | Charting | | Medium | Charted "expect altitudes" not coded into FMS have potential to increase workload and induce unexpected events. |
| 220 | RNAV Task Force | Bruce Tarbert | FAA | Procedure Design | DME/DME | Q Routes | High | DME gaps exist in some RNAV procedures. Should procedures require IRU (in addition to DME/DME) or should there be different MEAs? How should information be depicted when it's dependent on onboard equipment? |
| 221 | PARC | Bill Vaughn | Continental Airlines | Procedure Design | Equipment Capabilities | | High | Can parallel RNAV/RNP procedures be conducted simultaneously? Issues exist concerning navigation performance and track repeatability. |
| 222 | RNAV Task Force | | NASA | Procedure Design | Equipment Capabilities | | Medium | Intercept Angles: Equipment varies as to acceptable angle of intercept. Some don't accept more than 30 degree angles. |
| 223 | Checker 5 SID at CLT; SIDs at LAS | | FAA | Procedure Design | Equipment Capabilities | | High | Problems reported when waypoints in close proximity to departure end of runway or when radio updating occurred close to waypoint Aggressive bank angles have occurred. |
| 224 | PARC | Operations Panel | ICAO | Procedure Design | Flight Crew Procedures | | High | Current nav procedures for noise abatement often lead to high crew workload. The paths may be complex and the crew often needs to delay configuration changes to meet turn radius requirements. There may also be safety concerns. High pitch angles make it difficult to see VFR traffic underneath. Aircraft are kept slow (near maneuvering limits). |
| 225 | RNAV Task Force | Obstacle Clearance Panel WG | Obstacle Clearance Panel WG | Procedure Design | FMS (other) | | High | Should there be a maximum turn angle at the final approach fix? Variations exist for different RNAV systems. |

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| 226 | RNAV Task Force | Thomas Schneider | FAA | Procedure Design | RNAV Approaches | | High | What are the criteria for determining whether it's appropriate to use MDA (non-precision approach) as a DA for a VNAV approach? Should the DA minimums be above the MDA? |
| 227 | RNAV Task Force | Operations Panel | ICAO | Procedure Design | RNAV Approaches | | High | What are the obstacle clearance and flight crew issues pertaining to the use of a MDA as DA? |
| 228 | RNAV Task Force | Operations Panel | ICAO | Procedure Design | RNAV Approaches | Airline Procedures | Low | Although continuous descent final approaches are generally considered preferable to step downs, the latter may have advantages in some cases (e.g. icing, early alignment with runway requires greater rate of descent). Do guidelines exist for these cases? Should pilots be trained accordingly? |
| 229 | ASRS Review | Richard Barhydt | NASA | Procedure Design | RNAV SID/STAR | | High | RNAV SID/STAR that shares name with waypoint on another procedure has led to confusion and pilots occasionally flying the wrong procedure. |
| 230 | RNAV Task Force | RNAV Task Force | RNAV Task Force | Procedure Design | RNAV SID/STAR | | High | Several procedure design issues should be considered when conducting simultaneous RNAV departures: fly-by vs. fly over for initial fix, minimum height for initial turn, course change for initial turn. |
| 231 | RNAV Task Force | Bruce Tarbert | FAA | Procedure Design | RNAV SID/STAR | | High | Some procedure modifications can improve tracking performance (DFW cited as example): speed constraints, altitude revisions, bank angle limitations, waypoint track changes. Do procedure design guidelines exist for determining whether certain procedure features will improve tracking performance? Are there guidelines for when these techniques should be implemented or how they should be designed? Have design attributes that lower path tracking performance been identified? |
| 232 | RNAV Task Force | Bruce Tarbert | FAA | Procedure Design | RNAV SID/STAR | | High | Some waypoint and leg type combinations have led to unanticipated flight tracks. |

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| 233 | PARC Human Factors WG | PARC Human Factors WG | PARC Human Factors WG | Procedure Design | RNAV SID/STAR | | Medium | Speed restriction at initial waypoint seen as key mitigating factor in reducing turn anticipation errors. |
| 234 | RNAV Task Force | Ken Speir, Dennis Zondervan | Delta Airlines, ATL TRACON | Procedure Design | RNAV SID/STAR | | Medium | VA to CF and VI to CF legs being considered for ATL SID/STARs. Is there a benefit to one over the other? |
| 235 | CHECKER 5 report | | FAA | Procedure Design | RNAV SID/STAR | | Medium | Too many transition options caused pilot confusion in some cases. |
| 236 | AFS-410, operational exp, implementation meeting notes; TIMs | Terry Stubblefield | FAA | Procedure Design | RNAV SID/STAR | | High | Occasional impact of procedure design on interfering with checklist configurations, other cockpit tasks such as monitoring waypoints and speed/altitude restrictions. The 18-step process for developing a new procedure should help address this issue. A comprehensive and specific set of design guidelines that concentrates on human performance still appears to be needed. |
| 237 | Technical Interchange Meeting | Terry Stubblefield | FAA | Procedure Design | RNAV SID/STAR | | High | Potential for capture errors when different procedures share many of same initial stages or waypoints. |
| 238 | RNAV Task Force | unknown source | | Procedure Design | RNAV SID/STAR | | Medium | RNAV SIDs and conventional IFR departures may conflict with each other causing aircraft to come in close proximity to each other. |
| 239 | RNAV Task Force | | FAA | Procedure Design | RNAV SID/STAR | | High | The determination of whether to use a flyover or fly by waypoint and how close the first waypoint is to the runway end in a SID should be carefully analyzed so that deviations are minimized. |
| 240 | Technical Interchange Meeting | John Anderson | Continental Airlines | Procedure Design | RNAV SID/STAR | | High | Tight turns in procedure can lead to overshoot problems when aircraft is accelerating. Speed restrictions may be used to help mitigate problem. |

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| 241 | RNAV Task Force | Bruce Tarbert | FAA | Procedure Design | RNAV SID/STAR | Airline Procedures | High | What is the appropriate minimum distance to the first waypoint after departure? Unpredictable flight tracks may occur when LNAV is engaged at 1000 ft and a fly-over waypoint exists 0.5 NM from the departure end of runway. |
| 242 | PARC Human Factors WG | PARC Human Factors WG | PARC Human Factors WG | Procedure Design | RNAV SID/STAR | ATC Procedures | High | Some RNAV procedures won't work with radar vectors off runway (e.g. DFW SID that has initial waypoint 5 NM off runway) This design aspect may affect RNAV SID transition plans where procedures are introduced gradually by providing vectors off the runway. |
| 243 | RNAV Task Force | Frank Alexander | Northwest Airlines | Procedure Design | RNAV SID/STAR | DME/DME | High | What should be the minimum distance of initial fix from departure end of runway to enable adequate DME/DME updating? |
| 244 | RNAV Task Force | Bruce Tarbert | FAA | Procedure Design | RNAV SID/STAR | FMS Nav Database | Medium | Recommends implementation of heading to intercept path terminator (VI) for RNAV SID/STARs. Heading to altitude (VA) is currently used as a substitute. What are the ramifications of this substitution? |
| 245 | ASRS Review | Richard Barhydt | NASA | Procedure Design | RNAV SID/STAR | Training | High | Unconventional "at or below" restriction on RNAV SID is occasionally violated because it doesn't meet flight crew's normal expectation for altitude crossing restrictions in a climb. Awareness training may be warranted. |
| 246 | PARC Human Factors WG | | PARC Human Factors WG | Procedure Design | RNP Approaches | | High | How much of a preceding straight segment is needed for RF legs on final? |
| 247 | PARC | Jeff Williams, John McGraw | FAA | Procedure Design | RNP Approaches | | High | How much of a straight segment is needed before and after decision altitude? |
| 248 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | | High | Limiting procedure design to small set of ARINC leg types can lead to more predictable tracking performance. (RF legs are more predictable than fly-by turns). |
| 249 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | | Medium | Multiple CF legs can cause slight turns at waypoint (FMS converts from magnetic to true course). These slight turns can be disconcerting to the flight crew. Use of TF legs eliminates this problem. |

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| 250 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | | High | Naverus believes that the most complicated RNP procedures will still need to be designed as tailored procedures for a particular airline. Should there be complexity guidelines concerning when a particular approach is suitable for a public procedure? |
| 251 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | | High | Naverus-designed RNP approaches have final straight segment below 250 ft. (This height protects against the aircraft leaving the path when initiating a go-around (TOGA mode causes older aircraft to roll wings level).). Are there other considerations that should go into the minimum altitude for a turn segment? |
| 252 | PARC | Pedro Rivas | | Procedure Design | RNP Approaches | | Medium | What airspeeds should be assumed for RF legs based on each class of aircraft? |
| 253 | PARC | Pedro Rivas | | Procedure Design | RNP Approaches | | High | For a RNP approach, what is the minimum altitude in which the aircraft should be established on the extended runway centerline? |
| 254 | PARC | Jeff Williams, John McGraw | FAA | Procedure Design | RNP Approaches | | High | What should be the minimum altitude below which all segments are straight? (Document says 500 ft HAT). |
| 255 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | Airline Procedures | High | Naverus considers individual airline's procedures, aircraft types, and airports serviced when developing customized RNP approaches. How should these considerations be generalized when developing public RNP approaches? Public procedures should accommodate multiple flight deck platforms, procedures, and FMS types. |

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| 256 | Technical Interchange Meeting | | Naverus | Procedure Design | RNP Approaches | Airline Procedures | High | With RNP, it may be appropriate to revisit the definition of a "stabilized" approach. A potential revised definition may be that a stabilized approach requires the lateral and vertical trajectory to be managed by the system and be predictable to the operator. (A stabilized approach would continue to require final landing gear and flap configuration.) Will airlines and regulators be amenable to this or another proposed definition? Are any simulator studies needed? |
| 257 | PARC Human Factors WG | Kathy Abbott | FAA | Procedure Design | RNP Approaches | RNAV Approaches | High | Should identify visual perception issues for approaches where DA is reached in a turn (runway identification, potential disorientation coming out of clouds, VASI/PAPI alignment, etc.) |
| 258 | RNAV Task Force | Obstacle Clearance Panel WG | Obstacle Clearance Panel WG | Procedure Design | RNP Approaches | RNAV Approaches | High | What is the appropriate length of the final approach segment? |
| 259 | PARC Human Factors WG | PARC Human Factors WG | PARC Human Factors WG | Procedure Design | RPAT | Flight Crew Procedures | High | Will RNP aircraft be able to effectively identify ILS traffic on parallel runway? |

Issues Summary:

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| High | 144 |
| Medium | 96 |
| Low | 19 |
| Total | 259 |

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**14. ABSTRACT**

A transition toward a performance-based navigation system is currently underway in both the United States and around the world. Performance-based navigation incorporates Area Navigation (RNAV) and Required Navigation Performance (RNP) procedures that do not rely on the location of ground-based navigation aids. These procedures offer significant benefits to both operators and air traffic managers. Under sponsorship from the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA) has undertaken a project to document human factors issues that have emerged during RNAV and RNP operations and propose areas for further consideration. Issues were found to include aspects of air traffic control and airline procedures, aircraft systems, and procedure design. Major findings suggest the need for human factors-specific instrument procedure design guidelines. Ongoing industry and government activities to address air-ground communication terminology, procedure design improvements, and chart-database commonality are strongly encouraged.

**15. SUBJECT TERMS**
Human factors; RNAV; RNP; Instrument procedure design; Flight operations

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