HUMAN FACTORS CONSIDERATIONS FOR AREA NAVIGATION DEPARTURE AND ARRIVAL PROCEDURES

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Abstract

Area navigation (RNAV) procedures are being implemented in the United States and around the world as part of a transition to a performance-based navigation system. These procedures are providing significant benefits and have also caused some human factors issues to emerge. Under sponsorship from the Federal Aviation Administration (FAA), the National Aeronautics and Space Administration (NASA) has undertaken a project to document RNAV-related human factors issues and propose areas for further consideration. The component focusing on RNAV Departure and Arrival Procedures involved discussions with expert users, a literature review, and a focused review of the Aviation Safety Reporting System (ASRS) database. Issues were found to include aspects of air traffic control and airline procedures, aircraft systems, and procedure design. Major findings suggest the need for specific instrument procedure design guidelines that consider the effects of human performance. Ongoing industry and government activities to address air-ground communication terminology, design improvements, and chart-database commonality are strongly encouraged. A review of factors contributing to RNAV in-service errors would likely lead to improved system design and operational performance.

1 Introduction

1.1 Move toward Trajectory-Based Operations

In the U.S. National Airspace System (NAS) and elsewhere in the world, a move is underway to transform navigation services from those emphasizing the use of specific sensors to those focusing 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 with less regard to the location of ground-based radio stations.

RNAV is seen as a key enabling factor in improving the efficiency and capacity of the NAS [1]. It is also being used extensively in Europe [2]. 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].

RNAV is 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 common

with any transition, some human performance issues have emerged during operations.

Many of these issues are not unique to RNAV procedures. The new emphasis on trajectory-based operations has occasionally 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 Federal Aviation Administration (FAA) and administered by the National Aeronautics and Space Administration (NASA). FAA Advisory Circulars (ACs) such as 90-100 (RNAV Operations) are being developed to address them [5]. With discussions taking place in multiple venues and across a number of organizations, there appears to be a strong need to document RNAV-related human factors issues raised and lessons learned. These aspects can also be discussed in the context of ongoing or proposed positive actions designed to further improve overall system performance.

1.2 Study to Identify Human Factors Considerations

In response to these needs, the NASA Langley Research Center, under sponsorship from the FAA, has undertaken a project to document RNAV-related human factors issues and propose recommended areas for further consideration. The study has focused on RNAV terminal area operations including Standard Instrument Departures (SIDs) and Standard Terminal Arrival Routes (STARs). Discussion of operational challenges that have occurred is intended to improve awareness of human factors for NAS stakeholders who conduct RNAV terminal area operations. It also serves to provide general guidance to air navigation service providers and manufacturers when designing RNAV instrument procedures and supporting aircraft systems, respectively. Regulators may reference the material when developing certification guidelines for aircraft and flight crews involved in RNAV operations.

Results of this study focus primarily on human performance issues that have occurred during RNAV implementation. They are not intended to be a harsh critique of these operations or to imply 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 study. The reader is encouraged to consider the issues presented in light of the significant benefits offered by RNAV. Coordinated actions taken to address these issues will likely lead to even greater operational benefits.

2 Results of Human Factors Study

NASA investigated the occurrence of human factors issues for RNAV operations through discussions with expert users, a literature review, and a focused review of the ASRS database. Findings were subsequently reviewed by expert members of the air traffic, airframe manufacturer, and airline communities.

2.1 ASRS Review

Two NASA researchers conducted an independent review of the ASRS database for human factors-related events pertaining to RNAV departure and arrival procedures. The review focused on seven U.S. airports that have implemented RNAV SID and STAR

procedures: Boston, Charlotte, Dallas Ft. Worth, Philadelphia, Phoenix, Las Vegas, and Washington Dulles. One hundred twenty-four reports were reviewed for a period between 2000 and mid-2005. For each report, one or more categories were selected that were deemed to have contributed to the event. Categories and a partial list of attributes included:

- *Air Traffic Control Procedures*: terminology, phraseology, timing of clearance information, inter-facility coordination
- *Airline Operations*: training, company procedures, pilot actions, airline/flight deck communication
- *Aircraft System Capabilities*: equipment availability and performance, path tracking, mode transitions, navigation database
- *Procedure Design and Charting*: waypoint proximity, use of waypoint constraints, interference with non-RNAV procedures, chart clutter
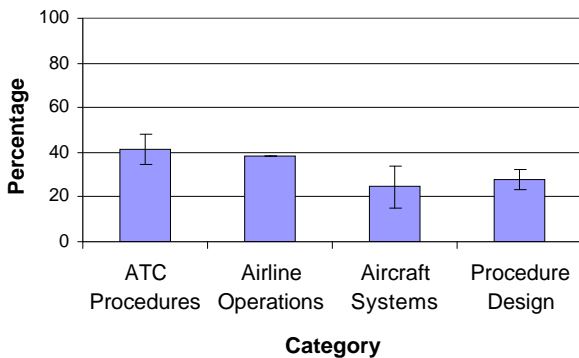

Fig. 1. Percentage of ASRS Reports Attributed to Each Category (May Have More than One Assigned)

Figure 1 shows the categorization of the selected reports based on the categories described above. The values are the mean percentages applied to each category by the two NASA researchers. Error bars represent plus or minus one standard deviation of the mean. Both researchers assigned the "Airline Operations" category to the same number of reports.

It should be noted that the vast majority of these reports were written by pilots. Only a few were found that were written by controllers.

Therefore, the report synopses normally reflect the involved pilot's perspective of the event. Researchers relied heavily on the synopses when assigning categories and were without the benefit of other perspectives of the same event.

These results highlight the importance of effective air traffic and flight procedures as well as the need for clear communication between all participants. The absence of available aircraft equipment or its non-use often plays as much of a role in operational success as the design attributes of existing equipment. Procedure design aspects appear to have an overall effect on system performance and may influence the presence of contributing factors in the other categories. The procedure design category was only assigned when a direct reference was made by the reporter or when a clear association could be made by the researcher.

2.2 Issue Category Discussion

All factors appear to influence the performance of a performance-based NAS.

2.2.1 Air Traffic Control Procedures

The introduction of RNAV procedures has led to opportunities for more route-oriented climb and descent clearances to be issued by Air Traffic Control (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. They have also revealed several aspects of existing ATC terminology that can occasionally lead to ambiguities.

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 addressing this gap through development of a "climb via" phraseology and procedure. Changes to the FAA Air Traffic

Control Order (7110.65R) [6] and the Aeronautical Information Manual (AIM) [7] 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 [6] and AIM [7] 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 procedures.

In response to changing air traffic needs, it may become necessary for controllers to change the assigned runway for a departing or arriving aircraft. This change requires the flight crew to perform several steps to re-program the aircraft's Flight Management System (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 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 these 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 Automated Terminal Information Service (ATIS) or Pre-Departure Clearance (PDC) has been discussed, but some have expressed concerns that these sources may cause confusion related to the clearance status of the information.

2.2.2 Airline Operations

2.2.2.1 Flight Crew Procedures
Flight crew procedures have been 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.

2.2.2.2 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.

2.2.2.3 Pre-Departure Clearance (PDC)
Problems may 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 over 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 reported pre-programming the FMS in anticipation of a preferred route or dispatch issued clearance and then failing to realize 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.

2.2.2.4 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-job 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 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.

2.2.3 Aircraft System Capabilities

Equipment design features and limitations often impact pilot performance and workload in a performance-based environment. Discussion of these issues is intended to help system designers when developing or enhancing their products and serves to make pilots and controllers aware of aircraft capabilities when conducting RNAV procedures.

2.2.3.1 FMS (Other than Navigation Database)

The FMS plays a key role in the implementation of performance-based navigation. Most FMS considerations related to RNAV 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 terminal procedures when using the FMS Vertical Navigation (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.

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 (KDFW), 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. FMS designs also vary in the way they construct 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.

2.2.3.2 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 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 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 operations to those aircraft that have map displays associated with Electronic Flight Instrumentation Systems (EFIS).

2.2.3.3 FMS Navigation Database

The FMS navigation database is likely the equipment component having 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 of this process. These problems can 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 an 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 [8]. Errors can be introduced through the arduous process of converting written data to an electronic format. They 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.

Errors can also be introduced when avionics manufacturers convert the ARINC 424 data into an FMS-readable format and provide them 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. 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 [9]. 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 AC 20.153 [10]. This guidance is expected to mitigate prior errors that occurred during the data transition process.

In addition to maintaining navigation database integrity, consistency between FMS databases and procedure charts is essential to mitigating excessive flight crew workload. Although significant progress has been made in reducing these discrepancies, some still exist. In response to the American Airlines Flight 965 accident [11], the National Transportation Safety Board (NTSB) recommended that charts, FMS navigation databases, and electronic map displays provide a consistent representation of navigation information [12].

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. The impact of navigation databases on RNAV operations suggests the need for continued vigilance regarding data integrity checking, commonality with charted procedures, and potential tracking differences across various systems.

2.2.4 Procedure Design

Procedure design plays an important role in making sure pilot and controller workload is manageable, human errors are kept to a minimum, and aircraft equipment enables pilots to fly the procedures as intended. These attributes are needed to achieve capacity goals while maintaining safety.

RNAV SID and STAR procedures offer airport planners greater flexibility to efficiently manage their airspace. 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 region, pilots balance procedure monitoring tasks with checklist usage, automation changes, and configuration changes among other things.

In order 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 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 [13]. Even when flyable, design factors may contribute to potential safety 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 among 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, but may also delay configuration changes after takeoff. Procedure designers should consider these tradeoffs. Close-in waypoints may be an issue for non-GNSS equipped aircraft. These aircraft may not have yet acquired a good position update after

takeoff. Good progress in these areas 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, the ASRS review revealed that traffic conflicts do occasionally occur as a result of interactions between the two procedure types. Interference has also been mentioned relative to Military Operating Areas (MOAs). A review of specific issues may be warranted.

Pilot errors 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.

3 Recommendations

In response to these findings, a number of emphasis areas are proposed in order to continue improving the effectiveness of RNAV SID and STAR procedures. Several U.S. and international committees are already considering some of these areas.

3.1 Human Factors Guidelines for RNAV Instrument Procedure Design

It appears that procedure design techniques are currently based primarily on obstacle clearance assessments, noise restrictions, and traffic flow management issues, with less emphasis being placed on flight operations. Eurocontrol's design document emphasizes the flyability of RNAV terminal area procedures and clarifies it is not intended to directly address operational issues [13]. Changes to FAA Orders 8260.46 [14] and 7100.9 [15] pertaining to SIDs and STARs provide some awareness of human performance issues based on lessons learned.

Terminal area and approach procedure designers could likely benefit from a set of comprehensive and specific design guidelines that consider flight crew and controller performance. This tool could be used as part of an overall package evaluated prior to the development of a new RNAV procedure. The guidelines could also be applied to current procedures, with recommendations made for improvement.

These guidelines should consider the human performance effects of design attributes such as those discussed in this study. Attributes include but are not limited to climb gradients, waypoint proximity, and the use of successive altitude restrictions. They should also consider ways for common elements between comparable procedures at an airport to be evaluated for their potential to cause misidentification (capture) errors.

These guidelines should be supported by a series of studies that identify tradeoffs between different design techniques, propose recommended limits, and consider interaction effects.

Considering the negative effects of high overall complexity, a study is recommended to develop a procedure complexity metric. An effort should be made to assess the effects of common design techniques and their interactions on overall complexity. FAA Orders 8260.46C [14] and 7100.9D [15] mention the importance of low complexity but do not seem to offer a specific metric. Recognizing that different airports present various design challenges, a review process is recommended for procedures that exceed a defined complexity threshold.

3.2 Continuation of Working Groups that Identify and Propose Solutions for Operational Problems Associated with RNAV SID and 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 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.

3.3 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 been identified as a primary issue.

3.4 Review of Contributing Factors to RNAV-related errors.

A comprehensive review of errors occurring during RNAV SID and STAR operations and their contributing factors should be undertaken. This review could concentrate on the effects of equipment design on these errors. If the review reveals that common deficiencies existed in aircraft instrument or avionics systems for these error cases, the FAA could consider revising the appropriate documentation. Potential changes to equipment requirements may also consider FMS capabilities to handle particular leg types and path terminators if a determination is made that the use of those capabilities would enhance flight crew performance or procedure applicability. The use of electronic map displays for RNAV should receive particular attention. In NASA's preliminary review of RNAV SID and STAR procedures, pilots often mentioned the lack of a map display as a contributing factor to high workload and in-service error conditions.

4 Conclusions

A transformation to a performance-based navigation system is underway worldwide. New RNAV 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 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 procedures. To ensure a seamless transition to performance-based navigation, a collaborative effort between all stakeholders is needed to mitigate in-service issues and to anticipate potential issues before introduction of new operations.

A strong desire to realize the benefits of RNAV 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 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 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 an important overall goal. Results of this study suggest that even relatively smaller coordination efforts along the way can also yield significant benefits. One human factors specialist has mentioned that different aspects of procedure design are handled by different groups within the FAA. If these groups don't coordinate effectively with each other, an incompatible design may result. Development of instrument procedure design criteria based on human performance considerations would provide a better link between the operational community and the procedure designers.

This study has 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 have common features with those raised in this study.

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