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HUMAN FACTORS ISSUES OF NAVIGATION REFERENCE SYSTEM WAYPOINTS

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As part of the Next Generation Air Transportation System initiative the Navigation Reference System waypoint grid was developed to realize additional benefits of area navigation. Despite industry and government involvement in the original design of the grid, it has been met by operators and air traffic controllers with limited enthusiasm. The FAA is sponsoring research to identify human factors issues that might explain this lack of usage and the development of mitigations or recommendations for those issues discovered. In this paper, we will discuss our initial examination of the Navigation Reference System and review potential recommendations to several areas for improvement with specific focus on changes to waypoint nomenclature.

The Next Generation Air Transportation System (NextGen) was initiated, in part, in response to a predicted two to three fold increase in air traffic by the year 2025 as compared to 2003 levels in the United States (Joint Program and Development Office [JPDO], 2007) (Federal Aviation Administration [FAA], 2009). However, the continued reliance on ground-based navigational aids in an environment with increasing air traffic density will limit the achievement of NextGen goals. Current ground based navigational aids are often placed near population centers leaving large geographical areas uncovered. This variable density in conjunction with traffic saturation in metropolitan areas sometimes forces a singular flow of traffic into merge points that are often responsible for system wide delays (Boetig & Timmerman, 2003), especially in the United States northeast corridor. Modern day operators with area navigation (RNAV) and satellite-based navigation abilities (i.e., Global Positioning Systems (GPS)) can now navigate directly to any point in space desired (FAA, 2006) and as such have increased flexibility regarding navigation decision making. Consequently, to fully gain the benefits offered with RNAV operations, the national airspace system as a whole must be designed to accommodate requests for more efficient direct routing. To meet this need, the FAA High Altitude Redesign (HAR) team developed the Navigational Reference System (NRS).

The Navigational Reference System

The NRS is a grid of approximately1600 RNAV waypoints that cover the continental United States and are defined through the intersection of lines of latitude and longitude (See Figure 1). To ensure a user friendly system, the development of NRS waypoint nomenclature was guided by the following objectives (Boetig & Timmerman, 2003; Hannigan, 2009).

- Be easy to communicate
- Have a low potential for error
- Be consistent with principles that guide names for navigational fixes
- Be intuitive as to the general location of the fix (i.e., provide “geographic” awareness)
- Incur only minimal changes to ground automation (i.e., database changes only)
- Support implementation across the United States
- Be easier to use than fixes delineated by full latitude and longitude coordinates

Additional considerations were that NRS waypoint names should be no more difficult than current waypoints to enter into FMS computers and flight planning software. Also, the NRS should utilize the currently underused RNAV capabilities of many aircraft in high altitude airspace, and the grid should be of sufficient density to support tactical use without significantly adding mileage to an aircraft’s route.

Traditionally named waypoints are comprised of five letters which are meant to be pronounceable (e.g. CURLY). The location of these waypoints are randomly assigned with the exception of certain waypoints associated with geographic or other local features such as the BEARZ waypoint near the city of Chicago referencing the Chicago Bears football team. In contrast, NRS waypoints consist of both letters and numbers and have a distinctive naming pattern in which geographical information is embedded in their name (described below). Because they include both letters and numbers, NRS waypoints are not pronounceable as a single word but rather require the pronunciation of each character separately (e.g. KD54K is pronounced as kilo-delta-five-four-kilo).

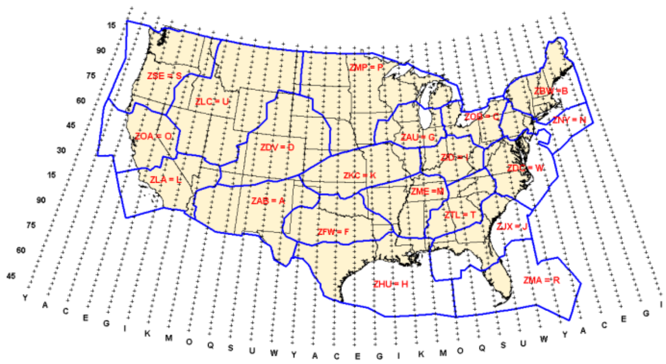

Figure 1. Current distribution of 1600 NRS waypoints and ARTCC regions (Borowski et al., 2004).

NRS waypoint names are composed of two letters followed by two numbers, followed by a single letter (See Figure 2). The first and second characters of NRS waypoints are the FIR identifier for the United States (“K”) and the FIR subdivision, or ARTCC center in which the waypoint is located (e.g. “D” for Denver ARTCC). The third and fourth characters are a number group representing the latitude of the waypoint. These numbers begin at the equator with *00* and advances north and south from *01* to *90* and correspond to every 10 minutes of latitude and repeating every 15°. The final character in the NRS waypoint is a letter representing the line of longitude for which the waypoint is located. This identifier starts at the prime meridian moving west to east and uses the letters *A* to *Z* while repeating every 26°. To date, the current density of the NRS grid is one waypoint spaced every 30 minutes of latitude and every 2° of longitude. Possible future expansion will space one waypoint every 10 minutes of latitude and 1° of longitude. This nomenclature system was intended to provide information to users about each waypoints geographic location: first within the United States, then within which ARTCC airspace, and then narrowed down even further to a specific line of latitude and longitude (See Figure 2).

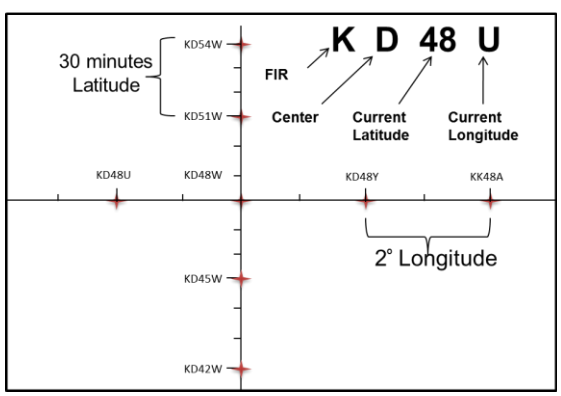

Figure 2. NRS waypoint grid structure and nomenclature.

To ensure the proposed nomenclature would offer the advantages already discussed, prior to deployment, the MITRE Center for Advanced Aviation System Development (CAASD) conducted a series of studies in which the use of the NRS grid was compared to traditional longitude and latitude coordinates. The results of this research found that the naming convention was rated as “easy to use” and “acceptable” by both controllers and pilots alike when compared to full longitude and latitude coordinates (Boetig, Domino, & Olmos, 2004; Borowski, Wendling, &

Mills, 2004; Domino, Ball, Helleberg, Mills, & Rowe, 2003; Domino, Boetig, & Olmos, 2004). Although it is recognized that the creation of any new navigation system is expected to produce a period of adjustment for all users, we have found an apparent industry wide reluctance to utilize the NRS grid despite the pre-deployment finding of grid and waypoint acceptability. Our research has revealed several human factors issues which may help explain why NRS waypoints have been underutilized.

NRS Human Factors Considerations

We evaluated the human factors issues of NRS waypoints from the multiple perspectives of those responsible for their development and current users including pilots, flight planners, dispatchers, flight management system (FMS) database managers, air traffic controllers, and air traffic control managers and supervisors. In addition to extensive interviews and site visits, we also completed an exhaustive review of the literature and incident and accident database searchers.

As in the studies conducted prior to NRS grid implementation (e.g., Domino, et al., 2003), we found that with sufficient information or training, those interviewed understood the intent and structure of both NRS waypoint names and grid structure. Pilots and controllers did not view NRS waypoints any differently than traditionally named waypoints when seeing them on a flight plan. Pilots did not believe NRS waypoints contributed to any particular CRM issues on the flight deck or required any changes to pilot flying and pilot monitoring roles and responsibilities. Dispatchers stated that NRS waypoints provide greater flexibility in route planning, especially in the western portion of the US where fewer ground based navigation aids exist and were enthusiastic about using them. Despite these positive aspects, there are several issues that explain their limited use.

One item we frequently heard from both controllers and pilots was that the lack of ability to overlay the NRS grid structure over their respective radar and navigation displays greatly reduced the usability of NRS waypoints in their daily operations. This limitation is only problematic for those NRS waypoints that are not currently part of the route of flight being flown. That is, NRS waypoints that are programmed into either the controller's and pilot's computer systems are displayed as they are part of the entered route of flight. Although this constraint provided little to no ramifications when flight planning for pilots (i.e., strategic use), both groups reported that their ability to use the NRS waypoints in a tactical fashion once a flight was underway was essentially nil. Examples of tactical use include short term deviations around small areas of intense weather or the creation of parallel traffic flows. It became clear to us that any future attempts to increase system wide NRS utilization must be accompanied by an improvement in display capabilities for pilots and controllers alike.

Pilots had additional challenges related to their use of the FMS that restricted practical NRS functionality such as the limited amount of memory available in many of the FMSs in aircraft currently being flown. Rapid expansion in RNAV procedures and corresponding RNAV waypoint development has significantly limited the amount of memory capacity available for the addition of NRS waypoints. To illustrate this limitation, one US air carrier we visited produced a map of the United States where large geographical sections of NRS waypoints had to be removed from their FMS databases due to memory space limitations. Essentially, they were forced to choose which parts of the country they felt they were most likely to utilize NRS waypoints and those areas where they were not. Because of this, they are not only losing the routing flexibility that NRS provides but also the additional burden that is placed on their pilots in not knowing which waypoints were in the database and which are not and for aircraft schedulers who must know in which parts of the country specific aircraft can be allowed to fly.

In summary, throughout our interviews with current users, we discovered that the NRS grid meets some of the expectations that the system was designed to offer. Most groups reported that to some degree they liked the NRS concept even if they had problems with the way it was currently implemented and several individuals stated that they use NRS waypoints during route planning. We found it remarkable that when examining these issues with all groups, there was significant commonality with respect to the operational challenges they faced when trying to utilize NRS waypoints. Issues related to waypoint naming convention (discussed below), the absence of NRS waypoints presented on displays, and charting issues permeated our data. Additional concerns such as Flight Management Systems (FMS) database restrictions and En Route Automation Modernization (ERAM) considerations were mentioned by pilots and air traffic controllers, respectively.

NRS Waypoint Nomenclature Considerations

We discovered that several of the issues already mentioned, and others that are covered in more detail in Burian, Pruchnicki, & Christopher (2010), pertained to waypoint nomenclature (i.e., approach to naming waypoints: KD54U). Members from both the flight deck and ATC communities reported that they found the NRS waypoint nomenclature problematic in its current form and contributed to difficulties in using NRS waypoints in their day-to-day operations.

One NRS waypoint communication issue that was hypothesized prior to data collection was that frequency congestion would be aggravated due to the increased time it takes to verbalize a NRS waypoint as compared to traditionally named RNAV waypoints (Borowski, et al., 2004). A named RNAV waypoint is typically a pronounceable one-, two-, or three-syllable word, however each character in a NRS waypoint name generally must be verbalized separately using the phonetic alphabet and numbers; with the exception that the two numerals denoting the latitude line can be phrased as two separate numbers or one (e.g., "54" can be spoken as "five- four" or as the single number "fifty-four"). Through our interviews and searches of Aviation Safety Reporting System (ASRS), airline Aviation Safety Action Program (ASAP), and Air Traffic Quality Assurance (ATQA) incident reports we failed to find any reports of concern over the time it takes to verbalize NRS waypoints over the radio. It is possible, however, that this may become a concern in the future if NRS waypoint tactical usage increases while still using voice communications (prior to data-link). Nonetheless, we did identify some communication concerns with regard to NRS waypoint nomenclature.

Consistent with the controllers in one of the MITRE CAASD pre-deployment studies (Domino, et al., 2003), our pilots and controllers alike felt that the inclusion of the letter "K" in front of each waypoint was cumbersome and unnecessary. This is especially true since NRS waypoints have not been adopted outside of the United States as originally expected. As discussed earlier, the second letter in NRS waypoint name are the single letter identifiers for the ARTCC in which the waypoint is located. It was intended that providing the ARTCC identifier as part of the waypoint name would help provide some degree of "geographical knowledge" to pilots and controllers, not only about the location of the waypoint but its relationship to the aircraft's route of flight. Our interviews with dispatchers, flight planners and controllers suggest that this nomenclature does in fact provide some degree of geographical knowledge to these populations of users. However, dispatchers and flight planners at some of the air carriers we visited still exhibited some difficulty in finding specific NRS waypoints on en-route charts despite knowing in which Center's airspace the waypoint was located and despite their having a good understanding of the grid structure (These difficulties went beyond issues in chart readability). Interviews with pilots confirmed our suspicions that ARTCC identifiers are not commonly known and provided little to no geographical awareness. Pilots also suggested that because ARTCC boundaries are irregularly shaped and are generally unknown to flight crewmembers, including an ARTCC identifier as part of an NRS waypoint name is of little utility. (Center airspace boundaries are indicated on en-route charts but they are not very conspicuous and flight crews typically depend upon electronic navigation displays, which do not show air space boundaries, rather than on paper charts during flight). Furthermore, the amount of airspace assigned to each ARTCC is quite large. Pilots we interviewed stated that even if they knew the ARTCC single letter identifiers, additional specificity would be required to assist them in actually locating a specific waypoint within that Center's boundaries.

The two numbers and single letter that signify latitude and longitude lines in NRS waypoint names should, in theory, provided this necessary specificity but many we interviewed found them to be of little help. One individual summed up particularly well the concerns expressed by many we spoke to:

> "The grid system, while generally understandable with a key diagram in hand, is not intuitive. It requires learning a new coordinate system that conflicts with an existing one. The pseudo-latitude is problematic to my 44 years of flying. The alpha (longitude) key at the bottom of the NRS [diagram] also seems counter-intuitive; it "increases" (alphabetically) in an easterly direction while actual longitude decreases... Most confusing though, I believe, may be the "latitude" number that is not the actual latitude. I understand the system's goal is greater precision, but believe it increases the potential for error and increased workload."

Furthermore, in a few ASAP reports we discovered that occasional transposition of characters within a waypoint occurred and that the similarity of waypoint names in a route could cause confusion and lead to data entry errors (e.g., KG78K-KP90G-KP09A).

Cognitive Limitations

When humans are presented with information that will be immediately used, this information is held in working memory. It is well understood that there are significant limitations to working memory capacity which can actually decrease during times of stress (Baddeley, 1987). Research has shown that on average, when not under stress, working memory capacity is seven, plus or minus two, “items” or “pieces” of data (7 ± 2; i.e., five to nine items; Miller, 1956). An item or “piece” of data might be a single “thing”, such as one digit in a person’s phone number, or it might actually be several “things” that together carry a single unit of meaning, such as several letters that together make up a person’s first name. Some information held in a person’s working memory that is full to capacity will have to drop out to make room for new information that must be remembered.

Working memory limitations have important significance with regard to the design of NRS waypoint nomenclature. A traditional RNAV waypoint name such as “AZELL” is one item or piece of data to hold in working memory because it spells a single pronounceable word. Although the word itself may be meaningless, because it forms a pronounceable “word,” it comprises a single unit of information. NRS waypoints, on the other hand, do not “chunk” together to form a single unit of information. The waypoint KD54U is comprised of three to five units of information. It is comprised of three units if: a) the initial “K” is ignored because all NRS waypoints begin with “K” so one does not need to commit it to memory, and b) the numerals signifying latitude are treated as a single number, thus: Delta – fifty-four – Uniform. It comprises five units of information when each character is remembered and the numerals are treated as two separate numbers, thus: Kilo – Delta – Five – Four – Uniform. Therefore, when considering verbal communication and the possible reliance on working memory until the information can be written down, entered into a FMS, or typed on a DSR keyboard, one NRS waypoint alone can come very close to filling human working memory capacity. Remembering two NRS waypoints in a spoken clearance could easily exceed this capacity.

When examining normal human working memory capacity and limitations, it is important to consider the environmental or operational context in which the requirement to hold information in working memory, until it can be acted upon occurs. That is, a 7 ± 2 working memory capacity may be more applicable to the environment in which it was discovered, the laboratory, rather than to other environments such as busy flight decks or air traffic control work stations, which are full of multiple concurrent tasks and distractions. The association found between errors in reading back a clearance, which is often held in working memory until it can be “read back,” (Barshi & Healy, 2002; Cardosi, 1993; Prinzo, Hendrix & Hendrix, 2006), has led to the recommendation that air traffic controllers include no more than three items of information when issuing a clearance (e.g., altitude, heading, new ATC frequency). This appreciation for the possible normal reduction of working memory capacity in typical aviation operations should be considered when evaluating any new recommended approaches to the naming of NRS waypoints.

Conclusion

Through the course of this study we discovered that although most individuals we spoke to understood and appreciated the intended advantages of the NRS waypoint grid, they felt that a number of issues impeded realization of those advantages. To ensure the greatest utility of the NRS gird, we suggest that the findings in this report be used as a starting point and that individuals representing all sectors of the NRS waypoint user community be involved in developing potential solutions. In particular, emphasis should be given to the human factors issues associated with NRS waypoint nomenclature and displays which contribute to the most significant limitations in use of the grid by pilots and controllers. A wide variety of solutions should be generated and explored such as changes to NRS waypoint nomenclature, changes to depiction of NRS waypoints on charts and displays, NRS waypoint applications in electronic flight bags, and the feasibility of retrofits or upgrades to FMS and DSR databases and displays, among others. The solutions that are proposed must be evaluated against proposed NextGen airspace changes (e.g., dynamic sector boundaries, generic airspace at high altitudes, etc.), and all potential solutions must be tested and validated, prior to adoption and implementation.

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References

Baddeley, A. D. (1987). *Working Memory.* Oxford, England: Oxford University Press.

Barshi, I., & Healy, A. F. (2002). The effects of mental representation on performance in a navigation task. *Memory & Cognition, 30*(8), 1189-1203.

Boetig, R.C., Domino, D.A., & Olmos, B.O. (2004). *Airline pilot usability assessment of the navigation reference system* (MTR 04W0000011). McLean, VA: MITRE CAASD, The MITRE Corporation.

Boetig, R.C., & Timmerman, J. (2003). *The HAR navigation reference system* (MP 03W0000152). McLean, VA: MITRE CAASD, The MITRE Corporation.

Borowski, M., Wendling, V.S., & Mills, S.H. (2004). *HAR NRS usability study final report* (MP 04W0000163). McLean, VA: MITRE CAASD, The MITRE Corporation.

Burian, B. K, Pruchnicki, S., & Christopher, B., (2010). *Human factors evaluation of the implementation of the navigation reference system (NRS) Phase 1 report.* FAA Office of Human Factors Research and Engineering NextGen Task,09-AJP61FGI-0101.

Cardosi, K. (1993). *An analysis of en route controller-pilot voice communications.* DOT Report no. DOT/FAA/RD-93/11. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.

Domino, D.A., Ball, C.G., Helleberg, J.R., Mills, S.H., & Rowe, D.W. (2003). *Navigation reference system (NRS) naming convention usability study preliminary findings.* McLean, VA: MITRE CAASD, The MITRE Corporation.

Domino, D.A., Boetig, R.C., & Olmos, B.O. (2004). *Corporate pilot usability assessment of the navigation reference system* (MTR 04W0000033). McLean, VA: MITRE CAASD, The MITRE Corporation.

Federal Aviation Administration. (2006). *Roadmap for Performance-Based Navigation: Evolution for Area navigation (RNAV) and Required Navigation Performance (RNP) Capabilities 2006-2025.* Washington, DC: FAA.

Federal Aviation Administration. (October 2009). *Play Book.* Air Traffic Control System Command Center, National Severe Weather Playbook. Effective October 22, 2009 to December 16, 2009.

Hannigan, M. (2009). *Navigational reference system (NRS) and performance based routing (PBR).* Presentation to the CNS Task Force.

Joint Planning and Development Office, (2007). *Concept of operations for the next generation air transportation system* (Version 2.0).

Miller, G.A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, 63, 81-97.

Prinzo, O. V., Hendrix, A. M., Hendrix, R. (2006). *The outcome of ATC message complexity on pilot readback performance.* DOT Technical Report no.DOT/FAA/AM-06/25. Washington, DC: U.S. Department of Transportation, Federal Aviation Administration.