TECHNICAL REPORT DOCUMENTATION PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Human Factors Evaluation of the Implementation of the Navigation Reference System (NRS), Phase 1		5. REPORT DATE March 11, 2010 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Barbara K. Burian, Shawn Pruchnicki, Bonny Christopher		8. PERFORMING ORGANIZATION REPORT
9. PERFORMING ORGANIZATION NAME AND ADDRESS NASA Ames Research Center Moffett Field, CA 94035		10. WORK UNIT NO. 11. CONTRACT OR GRANT NO. DTFAWA-10-X-80005
12. SPONSORING AGENCY NAME AND ADDRESS Federal Aviation Administration Office of NextGen Human Factors Division 800 Independence Ave, SW Washington, DC 20591		13. TYPE OF REPORT AND PERIOD COVERED Final Report 14. SPONSORING AGENCY CODE ANG-C1
15. SUPPLEMENTARY NOTES FAA Technical Point of Contact: Daniel A. Herschler, 202-267-9853		

16. ABSTRACT

NRS waypoints have been identified as essential features of RNAV Wind Routes and ATC Playbooks (Flow Evaluation Team, 2009) and the NextGen Air Traffic Management System more generally (Radio Technical Commission for Aeronautics [RTCA], 2009).In this study, we examined NRS waypoint human factors issues that exist with regard to their nomenclature or use since their deployment approximately five years ago. The focus of this study has been predominantly on the human factors issues of NRS Waypoints for flight deck operators, although some information about issues that exist for air traffic controllers also have been collected and analyzed. We found that pilots and controllers tend to think of NRS waypoints in the same ways in which they think of traditionally named waypoints when seeing them on a flight plan and pilots do not believe they contribute to any particular CRM issues on the flight deck or require any changes to pilot flying and pilot monitoring roles and responsibilities. Dispatchers, in particular, agreed that NRS waypoints provide greater flexibility in route planning, especially in the western portion of the US where fewer ground based navigation aids exist. The pilots we interviewed indicated that they restrict their usage of NRS waypoints to original flight planning only (i.e., a strategic use). They reported that when using them tactically while enroute, such as for a diversion around weather, their workload could become quite high. Another problem we learned about is that many flight management system (FMS) databases lack the storage capacity to hold all 1600 NRS waypoints in addition to all the other RNAV and named waypoints in the NAS. This creates a need for the flight crew to program waypoint locations using lat/long entries, which is time consuming, difficult, and prone to data entry errors. Controllers we interviewed mentioned that NRS waypoints cannot be displayed on their radar scopes and so visualizing a flight route that includes NRS waypoints is more challenging. Additional information about the NRS is available in FAA Order 7350.9, Chapter 1, Section 6, Paragraph W. (https://www.faa.gov/air_traffic/publications/atpubs/locid_html/chap1_section_6_paragraph_W.html)

17. KEY WORDS NextGen; instrument procedures; navigation reference system; navigation waypoints; navigation chart usability	18. DISTRIBUTION STATEMENT Distribution unlimited		
19. SECURITY CLASSIF. (OF THIS REPORT) Unclassified	20. SECURITY CLASSIF. (OF THIS PAGE) Unclassified	21. NO. OF PAGES 58	22. PRICE N/A

Form DOT F 1700.7 (08/72)

Human Factors Evaluation of the Implementation of the Navigation Reference System (NRS)

Phase 1

Final Report

Barbara K. Burian, Ph.D.
NASA Ames Research Center

Shawn Pruchnicki, M.Sc.
San Jose State University at
NASA Ames Research Center

Bonny Christopher, M.A.
San Jose State University at
NASA Ames Research Center

March 11, 2010

This work was funded through FAA AJP-61
Study: 09-AJP61FGI-0101

ACKNOWLEDGEMENTS

The authors of this report would like to thank the many people throughout the industry who took time out of their busy schedules to share their experiences and insight, assisted with obtaining information and setting up meetings, and provided feedback and guidance. In particular we would like to thank Brian Holguin, Dan Herschler, Terry Locke, Pat Somersall, Lee Brown, Mike Hannigan, Steve Bradford, Lynn Ray, Joe McCarthy, Gisele Mohler, Lt. Col. William Crowe, Michelle Duquette, Sherri Magyarits, Parimal Kopardekar, Shelley Pennington, Brian Will, Daniel Shaw, Gary McMullin, Chris Brown, Pete Elmore, Chris Dacey, Paula Venn, Bill Murphy, Ted Demosthenes, Andi Ramaker, Mark Steinbicker, Sally Frodge, Andrew Petersen, Melvin Smith, Larry Braaten, Mike Meredith, Arnol Ketros, and managers, staff, pilots, controllers, supervisors, flight planners, dispatchers, and researchers at UPS Airlines, American Airlines, Southwest Airlines, Skywest Airlines, Albuquerque Center, and MITRE.

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EXECUTIVE SUMMARY

As part of the Next Generation Air Transportation System (NextGen) initiative, a redevelopment of the high altitude airspace is underway to realize the benefits of RNAV navigational capabilities (Boetig & Timmerman, 2003). To correct the imbalance between the current relatively inefficient airspace design and the capabilities of more modern aircraft (i.e. RNAV), the FAA created the High Altitude Redesign (HAR) Program to address these concerns above 18,000 feet MSL (Boetig & Timmerman, 2003). The Navigation Reference System (NRS) and NRS waypoints were developed though this program.

NRS waypoints are RNAV waypoints which form a grid and are identified through the intersection of lines of latitude and longitude. Currently totaling around 1,600 waypoints, they are deployed in all 20 ARTCCs throughout the continental United States; current density is one waypoint spaced every 30 minutes of latitude and every 2^o of longitude. The NRS waypoint names developed which are in current use consist of two letters followed by two numbers and a final letter (ex. KD54U). The first letter “K” is the ICAO FIR for the United States. The second letter (“D”) represents the ARTCC airspace in which the waypoint is located. The two numbers (“54”) and the final letter (“U”) denote the lines of latitude and longitude, respectively, whose intersection define the waypoint.

NRS waypoints have been identified as essential features of RNAV Wind Routes and ATC Playbooks (Flow Evaluation Team, 2009) and the NextGen Air Traffic Management System more generally (Radio Technical Commission for Aeronautics [RTCA], 2009).

Purpose and Scope

The current study was conducted to examine NRS waypoint human factors issues that exist, if any, with regard to their nomenclature or use since their deployment approximately five years ago. The focus of this study has been predominantly on the human factors issues of NRS Waypoints for flight deck operators, although some information about issues that exist for air traffic controllers also have been collected and analyzed. Only issues that exist relative to the current structure, deployment and use of NRS waypoints (i.e., at FL180 and above, 1600 point density) have been examined. This is the first phase of a three part study; subsequent phases will involve the development of solutions identified during this phase and focus on potential human factors issues related to an expanded NRS waypoint grid (e.g., below FL 180, 6600 point density).

Findings

Positive Aspects. We found that, with sufficient information or training, those we interviewed understood the intent and structure of both NRS waypoint names and the NRS grid structure. Pilots and controllers tend to think of NRS waypoints in the same ways in which they think of traditionally named waypoints when seeing them on a flight plan and pilots do not believe they contribute to any particular CRM issues on the flight deck or require any changes to pilot flying and pilot monitoring roles and responsibilities. Dispatchers, in particular, agreed that NRS waypoints provide greater flexibility in route planning, especially in the western portion of the US where fewer ground based navigation aids exist. Despite these positive aspects, a number of the advantages of the navigation reference system expected by Boetig and Timmerman (2003) and others have not been realized, at least not yet.

Negative Aspects. The pilots we interviewed indicated that they restrict their usage of NRS waypoints to original flight planning only (i.e., a strategic use). They reported that using them tactically while enroute (such as for a diversion around weather), their workload could be come quite high due to:

- increased frequency congestion (NRS waypoints take longer to verbalize than named waypoints)
- human working memory limitations (due to their structure, NRS waypoints create a greater demand on working memory than named waypoints do)
- lack of geographical knowledge about waypoint locations,
- lack of waypoint MFD display capabilities
- paper chart readability issues, and
- the increased potential for waypoint entry errors in the FMS.

Another significant problem found pertains to FMS database limitations; many databases cannot hold all of the NRS waypoints currently identified (1600) in addition to all the other RNAV and named waypoints needed.

Air Traffic Controllers, supervisors, and managers we interviewed also identified a number of negative aspects of NRS waypoints:

- NRS waypoints cannot be displayed on their radar scopes
- NRS waypoints can be displayed on URET but must be mentally transposed to the radar scope in operational use
- controllers are unable to determine bearing and distance between target aircraft and NRS waypoints on their radar
- they have difficulty visualizing the location of NRS waypoints within their sectors and visualizing an aircraft's route should the flight crew wish to divert to an NRS waypoint outside of their sector
- having to shift back and forth between alpha and numeric characters on the DSR keyboard to enter NRS waypoint names is cumbersome, and
- they have to be careful not to make a data entry error because the numeric portion of the DSR keypad is laid out differently than number keypads on computer keyboards.

Additional concerns regarding the use of NRS waypoints under NextGen, such as the possible degradation of GPS capabilities which are needed for aircraft to navigate to them and dependency upon critical DMEs as a back-up to GPS, were also identified.

1.0 INTRODUCTION

In the United States by the year 2025, it is predicted that there will be a two- to three-fold increase in air traffic as compared to 2003 levels (Joint Program and Development Office [JPDO], 2007, Federal Aviation Administration [FAA], 2009). As such, the continued reliance on ground-based navigational aids will increasingly challenge the successful movement of air traffic. Currently, ground based navigational systems have limited range, are in seemingly random locations (see Figure 1), and provide a rather chaotic distribution of airways and intersections. However, with the advent of area navigation (RNAV) and satellite-based navigation abilities, airspace users can now navigate directly to any point in space they desire (FAA, 2006). This capability essentially removes operator dependence on ground-based navigational aids and their numerous associated limitations. However, to fully gain the benefits of RNAV operations, the national airspace system must be designed to accommodate requests for the more efficient direct routing.

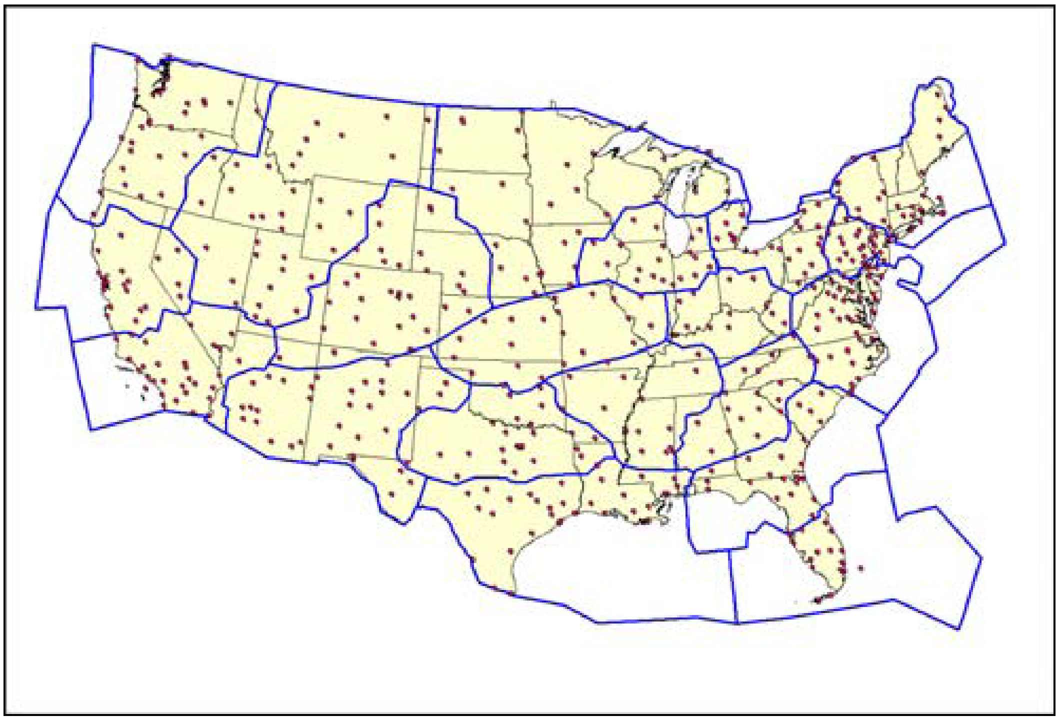

Figure 1. Current distribution of high altitude very high frequency omni-directional radio range (VORs) in the US by ARTCC Region (Laydon & Powell, 2003).

As part of the Next Generation Air Transportation System (NextGen) initiative, a redevelopment of the high altitude airspace is underway to realize the benefits of RNAV navigational capabilities (Boetig & Timmerman, 2003). To correct the imbalance between the current relatively inefficient airspace design and the capabilities of more modern aircraft (i.e. RNAV), the FAA created the High Altitude Redesign (HAR) Program to address these concerns above 18,000 feet MSL (Boetig & Timmerman, 2003). The HAR Program addressed several navigational features including:

- Pitch and Catch Points
- Area Navigation (RNAV)
- Non-Restrictive Routing (NRR)
- Waypoints for Special Use Airspace (SUA)
- Parallel RNAV Routes
- Air Traffic Control Assigned Airspace (ATCAA) avoidance
- Navigation Reference System (NRS).

The Navigation Reference System and NRS waypoints, the focus of this report, remain important components of the High Altitude Airspace Management (HAAM) Program, the successor program to HAR (Pat Somersall, personal communication, November 2, 2009). NRS waypoints have also been identified as essential features of RNAV Wind Routes and ATC Playbooks (described later; Flow Evaluation Team, 2009) and the NextGen Air Traffic Management System more generally (Radio Technical Commission for Aeronautics [RTCA], 2009).

NRS waypoints form a grid and are identified through the intersection of lines of latitude and longitude. They were first introduced into the National Airspace System (NAS) in 2005 and were limited to approximately 600 waypoints in seven northwest Air Route Traffic Control Centers (ARTCC). Since then, more waypoints have been added (currently totaling around 1,600) and are now deployed in all 20 ARTCCs throughout the continental United States (see Figure 2). The current density is one waypoint spaced every 30 minutes of latitude and every 2^o of longitude.

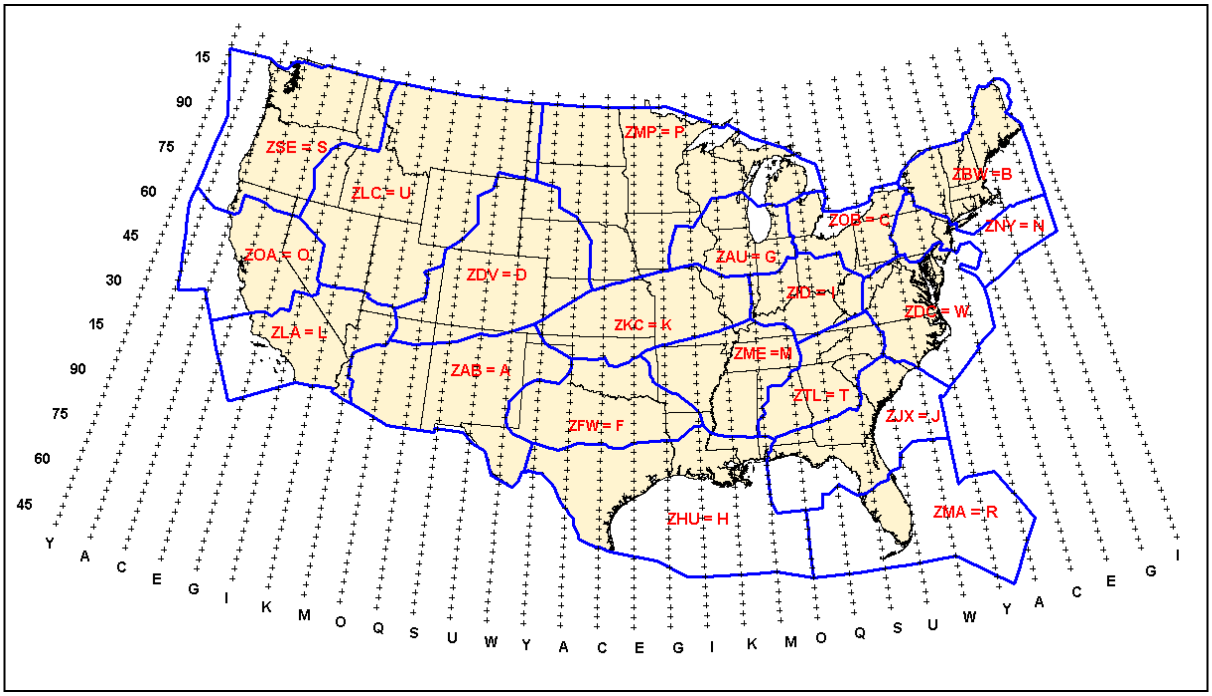

Figure 2. Current distribution of 1600 NRS waypoints and US ARTCC regions (Borowski, Wendling, & Mills, 2004).

As planned, they are currently only available for use in the high altitude regime (18,000 ft MSL and above) with the possible eventual goal to utilize them in lower altitudes, including within the terminal environment, and at greater density (spaced every 10 minutes of latitude and 1^{o} of longitude).

The motivation behind the development of this system was to facilitate user preferred routing while minimizing communication and data entry complications (i.e., entry errors & frequency congestion) of waypoints defined by full latitude and longitude coordinates. The hope was that the NRS waypoint system would allow both increased flexibility in a strategic sense for flight planning and tactically as a rerouting tool[1]. Hannigan (2009a) summarized the following expected benefits of NRS waypoints:

- Facilitate user preferred routing that is based on satellite navigation
- Reduce pilot and ATC workload regarding communication and chance for error
- Tactical aid to resolve traffic conflicts
- Tactical aid in weather avoidance that may provide closer routing to original flight path
- Satisfy processing requirements for filing at least one fix per ARTCC.

1.1 NRS Waypoint Nomenclature

A number of issues were considered when the NRS waypoints were first developed (Boetig & Timmerman, 2003; FAA 1999). For example, in part because of inherent design limitations with aircraft flight management systems (FMS), it was decided that the NRS waypoint names should adhere to standards for waypoint naming conventions and should be 5 characters in length, just as traditionally named waypoints are (see ARINC 424 Standards).

Those who developed the NRS waypoint nomenclature were guided by a number of objectives (Boetig & Timmerman, 2003; Hannigan, 2009a). The waypoint names should:

- 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)
- Minimize impact to airborne equipment
- Be usable by a majority of current aircraft
- Incur only minimal changes (i.e., database only) to ground automation
- Support implementation across the United States
- Be easier to use than fixes delineated by full latitude and longitude coordinates.

[1] Through interviews with individuals across the industry, we found that “strategic” is defined as NRS waypoint usage during flight plan construction by pilots or dispatchers, pre-planed alternative routing by traffic management units (TMUs), or by the use of wind routes or other flow management plans such as those in the FAA National Playbook. In contrast, “tactical” use is the assignment by air traffic control or the request by a pilot to divert to an NRS waypoint while an aircraft is enroute.

Further, it was desired that waypoints should be easy to enter into FMS computers and flight planning software, should utilize the currently underused RNAV capabilities of many aircraft in high altitude airspace, and that the NRS grid should be of sufficient density to support their tactical use without significantly adding mileage to an aircraft's route.

The NRS waypoint names developed which are in current use consist of two letters followed by two numbers and a final letter (ex. KD54U; see Figure 3).

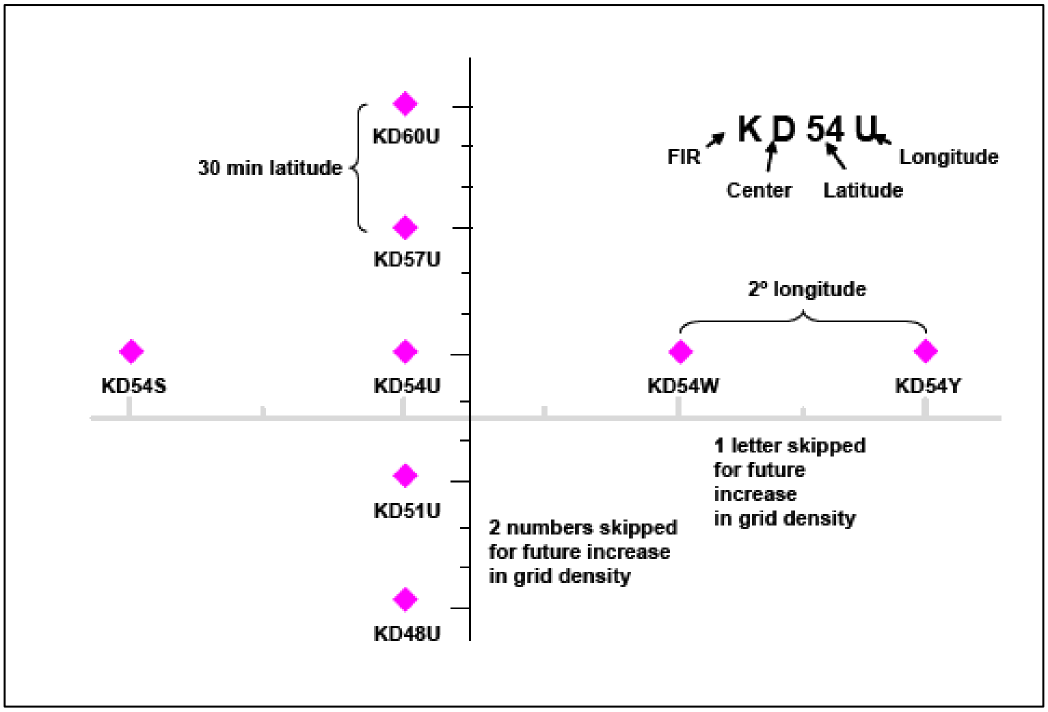

Figure 3. NRS waypoint grid structure and nomenclature (Boetig, et al., 2004, pg.2-2).

The first letter of each NRS waypoint is always a "K" and signifies that the waypoint is located in the contiguous United States. It was initially anticipated that this navigation system might be expanded on an oceanic or even global scale. Thus, "K" was used as the initial letter in the waypoint name in order to be compliant with ICAO standards.

The second letter signifies the ARTCC in which the waypoint is located. In the example in Figure 3, the "D" in KD54U indicates that its location is within the Denver ARTCC airspace. (See Table 1 below for a list of the single letter ARTCC identifiers.)

Following the ARTCC identifier is a two-digit numeric group representing the latitude of the waypoint (54 in the example, KD54U). Beginning at the equator with 00, latitude identifiers range from 01 to 90 and corresponds to every 10' of latitude and repeat every 15^{o}. Thus, the number 90 in an NRS waypoint (e.g., KH90G) "could represent 15^{o}, 30^{o}, 45^{o}, 60^{o} or 75^{o}" of latitude (Boetig, Domino & Olmos, 2004; pg. 2-2). To allow for further expansion of the grid in the future, only every third number is used in current NRS waypoint names (i.e., 03, 06, 09, 12 and so on).

The final letter in an NRS waypoint name signifies the line of longitude on which the waypoint is located. The prime meridian is labeled with the letter A and the letters repeat every 26^{o} of longitude. Recall that current grid density identifies a waypoint at every 2^{o} longitude. Therefore, every other letter in the alphabet is currently omitted in NRS waypoint names to allow for future expansion of the grid to a waypoint every 1^{o} of longitude in the future (see Figure 3).

A-Albuquerque	I- Indianapolis	P-Minneapolis
B-Boston	J- Jacksonville	R-Miami
C-Cleveland	K-Kansas City	S-Seattle
D-Denver	L-Los Angeles	T-Atlanta
F-Ft.Worth	M-Memphis	U-Salt Lake
G-Chicago	N-New York	W-Washington
H-Houston	O-Oakland	

Table 1. One letter identifiers for air route traffic control centers in the US (Borowski, Wendling, & Mills, 2004).

The creation of any new navigational grid system is expected to produce a period of adjustment for all users. However, studies completed by the MITRE Center for Advanced Aviation System Development (CAASD) prior to NRS waypoint deployment found that the naming convention was rated as "easy to use" and "acceptable" by both controllers and pilots alike (Boetig, Domino, & Olmos, 2004; Borowski, Wendling, & Mills, 2004; Domino, Ball, Helleberg, Mills, & Rowe, 2003; Domino, Boetig, & Olmos, 2004). Despite this pre-deployment finding of estimated acceptability, our research has revealed several human factors issues which are discussed in later sections.

2.0 PURPOSE OF THE STUDY

Prior to the deployment of NRS waypoints in the NAS, a number of studies were conducted by researchers at the MITRE Corporation examining the usability of the system constructed (Boetig, et al., 2004; Borowski, et al., 2004; Domino, et al., 2003; Domino, et al., 2004). During those studies, a number of human factors issues were identified for both pilots and air traffic controllers with regard to the composition and structure of NRS waypoint names and their general usability. At the time, the researchers hypothesized that a number of those issues would be resolved with more complete training and greater exposure to and increased comfort with the NRS waypoint system.

The current study was conducted to examine NRS waypoint human factors issues that exist, if any, now that they have been in use in the NAS for approximately 5 years.

2.1 Scope

The focus of this study has been predominantly on the human factors issues of NRS Waypoints for flight deck operators, although some information about issues that exist for air traffic controllers also have been collected and analyzed. Only issues that exist relative to the current structure, deployment and use of NRS waypoints (i.e., at FL180 and above, 1600 point density) have been examined.

Although we use the expression "this study" throughout this report, the endeavor and findings described actually represent the first phase of three phase study. In the second phase, to be completed in January 2011, recommendations will be made with regard to responding to the NRS waypoint human factors issues identified during this first phase. In the third phase, possible human factors issues in the expansion of NRS waypoints below the flight levels (i.e., below 18,000 ft.) and at a higher density (i.e., 6600 waypoints spaced every 10' of latitude and 1^{o} of longitude) will be examined.

3.0 APPROACH

We consulted numerous individuals and a wide range of resources to locate information about existing NRS waypoint human factors issues. Throughout this project we identified and reviewed high altitude enroute navigation charts and pertinent literature, studies, white papers, presentations, minutes of meetings, and other similar documents, as well as information located on websites and in training CDs and videos.

We conducted searches of the Aviation Safety Reporting System (ASRS), Airline Safety Action Programs (ASAP), and Air Traffic Quality Assurance (ATQA) databases[2] to locate incident reports involving NRS waypoints (see Appendix 2 for a complete list of the search terms used). We also gathered information about navigation grid systems used within the US military Global Area Reference System (GARS) and in the Gulf of Mexico.

A large part of our time was spent meeting with and interviewing professionals with direct, first hand knowledge of the development, deployment, and use of the NRS waypoint system. (See Appendices 3 and 4 for the questions we used to guide these semi-structured interviews.) We interviewed multiple individuals at the Air Traffic Control System Command Center (ATCSCC, "Command Center"), MITRE CAASD, (who conducted the pre-deployment studies of NRS waypoint usability), three domestic air carriers who are the greatest users of NRS waypoints, a domestic air carrier who makes minimal use of NRS Waypoints, and the Albuquerque ARTCC (Center).

At the air carriers we visited, all multi-crew operations conducted under 14 CFR Part 121 or Part 91, we interviewed line and management pilots, instructors, RNAV and ASAP program managers, safety managers, FMS database managers, flight planners, and dispatchers. At Albuquerque Center we interviewed air traffic controllers and air traffic management coordinators, officers, and supervisors.

We also interviewed a number of individuals from other organizations: pilots from international air carriers (i.e. non-US carriers) who use NRS waypoints in their flight plans, and pilots and managers at a domestic air carrier and a domestic fractional ownership operation who have made the considered decision not to use NRS waypoints in their operations.

Originally, we had also intended to observe controller and pilot (non-jeopardy) training in which NRS waypoints were covered or utilized. We had also planned to perform jumpseat observations aboard domestic air carriers who are the greatest users of NRS waypoints to observe NRS waypoints in actual use. However, as described in later sections, we learned in the course of this study that the ways in which NRS waypoints are trained and used made conducting these planned observations unlikely to yield interesting and meaningful information.

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[2] We found no ASRS reports directly related to NRS waypoints but several that pertained to related issues such as FMS data entry errors. We also found no ATQA reports related to NRS waypoints, possibly due to limitations related to the structure and "searchability" of the ATQA database. Because it is believed that such reports may indeed be located within this database, at the request of this study's sponsor, a refined search strategy will be employed and any findings will be reported in the second phase of this study.

4.0 FINDINGS

The sections below report the findings of this study. Current NRS waypoint depiction, training, and use by aircraft operators and air traffic controllers are described first. These sections are then followed by detailed descriptions and analysis of the positive and negative aspects of NRS waypoints found through the course of this study.

4.1 Current NRS Waypoint Depiction

4.1.1 NRS Waypoint Depiction for Aircraft Operators

4.1.1.1 Cockpit Displays

Although not required for RNAV operations, aircraft operators who use glass cockpit technology combined with a FMS have the ability to depict their route of flight on multi-functional displays (MFD). Current systems do not have the ability to overlay the NRS waypoint grid on an MFD. Only NRS waypoints that are part of an active flight plan that is programmed into the FMS can be visualized on the MFD. Thus, despite advanced flight deck technology, pilots must still resort to paper charts to locate and identify NRS waypoints that are not a part of their flight plans. Once a desired NRS waypoint is determined it must be entered into the FMS before it will be displayed on the MFD. This cumbersome process will be discussed below in the Negative Aspects of NRS waypoints section as it hinders the tactical utilization of NRS waypoints by today's flight crews.

4.1.1.2 Paper Enroute Charts

Depiction of NRS points on paper charts varies in both attributes and conspicuity depending on the chart vendor. On Jeppesen high altitude enroute IFR charts, NRS waypoints are printed in black ink on light green lines of longitude (see Figure 4). On NACO high altitude enroute IFR charts they are printed in very faint green connected by light blue lines of longitude. Since the current NRS waypoint system is only used at 18,000 ft and above, they are only found on the high altitude enroute IFR charts.

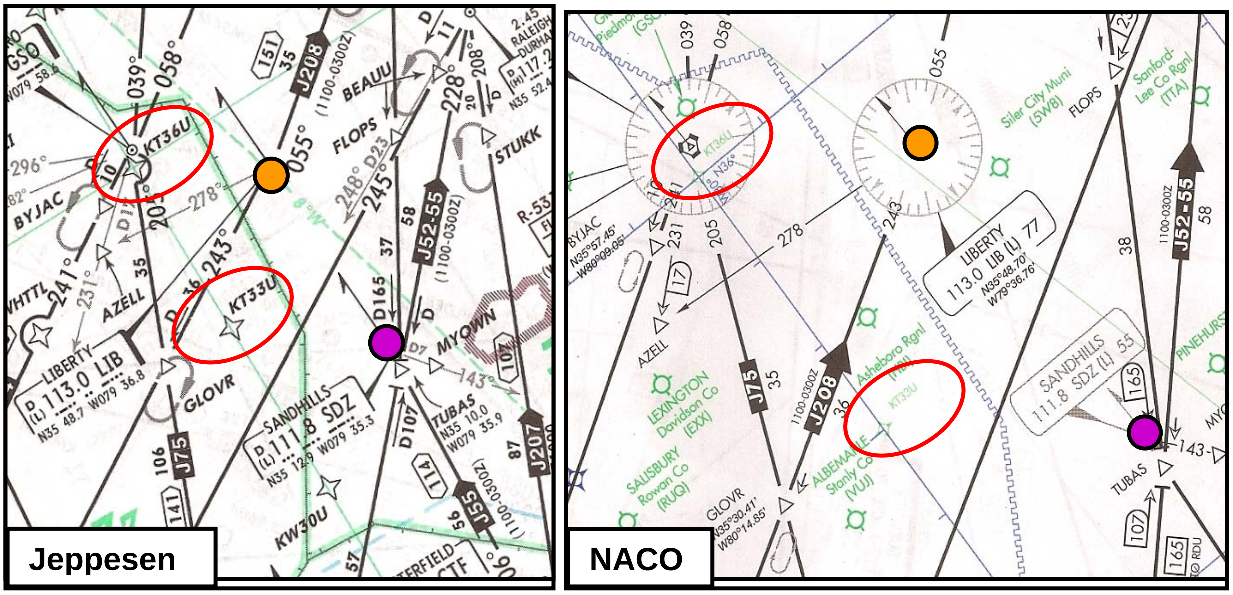

Figure 4. Jeppesen and NACO high altitude enroute charts (NRS waypoints are circled in red) (Burian, 2010).

4.1.2 NRS Waypoint Depiction for Air Traffic Controllers

Currently, the display systems used by Center controllers do not have the ability to display NRS waypoints that are not part of an aircraft's cleared route of flight. In other words, ATC is not able to overlay the NRS waypoint grid on their radar scope (see Figure 5).

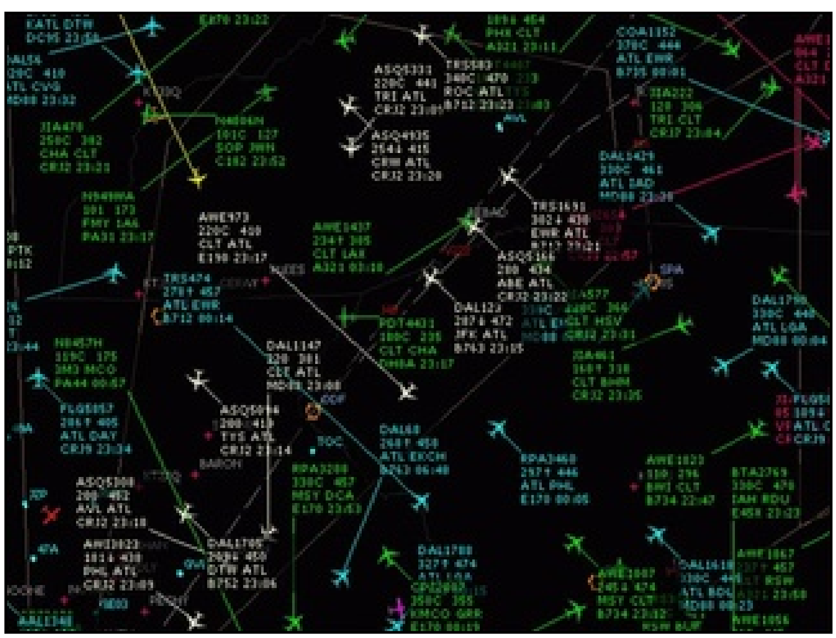

Figure 5. Busy ATC radar screen (Media2.MyFoxAtlanta.com, 2009).

This is in contrast to their current ability to show other RNAV fixes such as intersections and ground based navigational aids. This problem is identical in concept to the display limitations that flight crews face. However, controllers have the advantage of another electronic charting option with regard to NRS waypoints. The User Request Evaluation Tool (URET) can show NRS waypoints if selected to do so and can be used to determine waypoint location and to tactically develop a new route, if desired (see Figure 6). Implementation of URET is to be complete in all 20 ARTCCs in the contiguous United States during 2010 (FAA, 2010). However, the system is not incorporated directly into the controller's primary traffic display (radar scope) and resides in a secondary display next to the controller work station (see Figure 7).

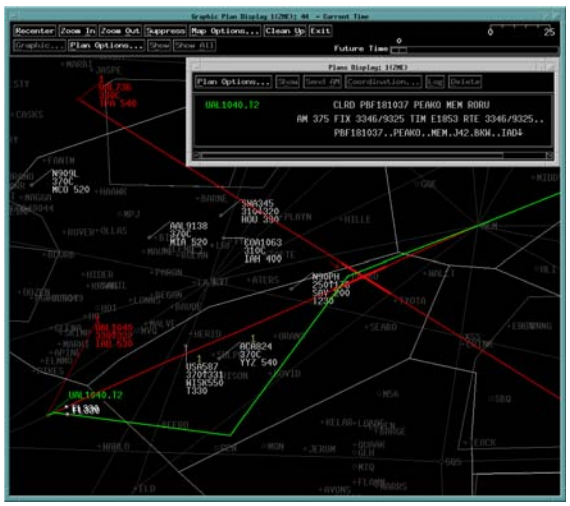

Figure 6. URET display (McFarland, 1987).

Figure 7. URET (circled) in an air traffic controller work station (McFarland, 1987).

4.2. Training

4.2.1 NRS Waypoint Training for Aircraft Operators

Within the area of aircraft operations, we found that NRS waypoint training appears to be quite minimal. Those at the airlines we spoke to were not able to recall having received any specific pre-NRS waypoint deployment information from the FAA but learned of them through their exposure to the National Route Program (NRP) and other HAR initiatives. They used various training methods to introduce NRS waypoints to their two main employee groups who would be affected by them: pilots and dispatchers/flight planners.

Pilot initial training about and exposure to NRS waypoints tended to be accomplished through the distribution of a "read before you fly" bulletin, if it occurred at all. One airline that we interviewed said that NRS waypoint training was achieved only through such a bulletin and believed that approach to training this information was sufficient. A check-airman we interviewed at another airline disagreed and believes the topic should be covered in ground school and in simulator training so that crews can learn to apply these waypoints tactically.

In contrast to the “bulletin-only” approach, one airline we spoke to included a NRS waypoint module in their new hire and captain upgrade classes soon after NRS deployment. This training module included the viewing of a FAA NRS waypoint video (FAA, no date-b) and they discussed the naming convention in class. That same airline also used to briefly review NRS waypoints in their pilot recurrent ground school. Currently, however, this topic is no longer covered in any of their training classes. At a third airline, that is a relatively heavy NRS waypoint user, the pilots interviewed reported that they had received no training or information at all with regard to NRS waypoints and demonstrated little understanding of NRS waypoint nomenclature or grid structure during our interviews with them.

At most of the airlines, even at those which provided some NRS waypoint exposure through a bulletin, pilots reported being surprised when these waypoints started showing up in their flight plans; initially, many calls were made to dispatchers for an explanation. Eventually, through exposure, bulletin, or ground school pilots we interviewed said they have become familiar with them, although the level of their knowledge about NRS waypoint nomenclature and grid structure clearly varied.

NRS waypoint training for dispatchers was also rather haphazard. For example, at one airline a route planner was asked by an ARTCC supervisor why they were not using NRS waypoints during a routine phone call. Prior to this phone call he had never heard of them and took it upon himself to learn more about them. With time he began to utilize them in the new routes he created and he trained each dispatcher in the company, one-by-one, when these waypoints were used in their flight plans for the first time. The route planner now uses them extensively in his route planning duties. Dispatcher “training” at the other airlines we interviewed was similar; in one case a supervisor attended a HAR meeting and returned to his airline to educate each dispatcher on a one-by-one basis. Their pilots began to query the dispatchers about the NRS waypoints in their flight plans and eventually a bulletin was released. In most cases, the dispatchers said they would use them more often but felt they got “push-back” from air traffic controllers who “did not appear to understand them.”

NRS waypoints are now included in several standard and custom route-planning software programs (e.g., Lido) and dispatchers and pilots at airlines who are heavier users are familiar with them and relatively comfortable with them although they differ in their preferences for using them. Dispatchers and flight planners tend to “like” them better than pilots because they provide greater flexibility for planning routes. Pilots we interviewed generally tended to express dislike for them because of several cumbersome usability issues described in later sections.

In any event, it is clear that initially aircraft operators had varying levels of exposure to and knowledge and understanding of NRS waypoints and the grid structure; most did not have a clear plan for how they would integrate this navigational tool into their flight operations.

4.2.2 NRS Waypoint Training for Air Traffic Controllers

In 2004, prior to NRS waypoint deployment, air traffic controllers at one ARTCC received an initial briefing on the basic concepts of the system. Topics such as the design of the waypoint grid and naming methodology were discussed. We learned that although the controllers thought the training they received was generally good, it lacked emphasis on how to apply NRS waypoints in their sectors to most effectively enhance traffic flow. They posited that NRS waypoint usage by controllers might be higher if such an emphasis during training was given.

When air traffic controllers qualify on a new sector, they are required to successfully draw the sector with all navigation fixes in their correct location and relationship to each other. This includes all airports, VORs, airways, and the like, but does not include the drawing of any NRS waypoints that fall within the sector. During interviews, air traffic controllers suggested that a greater emphasis on learning NRS waypoint locations in their sectors might result in them using the waypoints more often, particularly when faced with certain tactical situations, such as re-routing an aircraft to accommodate other traffic or deviating around weather.

Monthly computer-based instruction (CBI) is one method by which controllers receive recurrent training. We reviewed a CBI NRS waypoint training module for Center controllers and found that it provided a good overview of the NRS and naming convention. However, it lacked any guidance on how controllers can utilize this system to the fullest extent in a strategic or tactical sense. Hence, controllers may not appreciate how this system can at times offer advantages over traditional waypoints. However, significant human factors issues with their usability (discussed later) likely also contributes to any underutilization of them on the part of controllers.

4.3 Current NRS Waypoint Usage

The extent of NRS waypoint usage among aircraft operators is highly variable and ranges from thousands of flight plans filed monthly which include at least one NRS waypoint to the other end of the continuum which includes operators who have decided to not utilize the system at all. Figure 8 illustrates NRS waypoints with the greatest and least usage across all air carrier flight plans filed during a one month period. As you can see, very few NRS waypoints are used east of the Mississippi River.

Very little guidance exists with regard to certification issues or operational use of NRS waypoints in the NAS. Reference to NRS waypoints can be found in a few sections within the Aeronautical Information Manual (AIM; U.S. Department of Transportation, 2010) but no section in the AIM is devoted specifically to a description of NRS waypoint nomenclature, the grid, and strategic and tactical use of NRS waypoints. In Advisory Circular 90-100A, *U.S. Terminal and En Route Area Navigation (RNAV) Operations* (FAA, 2007a), NRS waypoints are not mentioned at all.

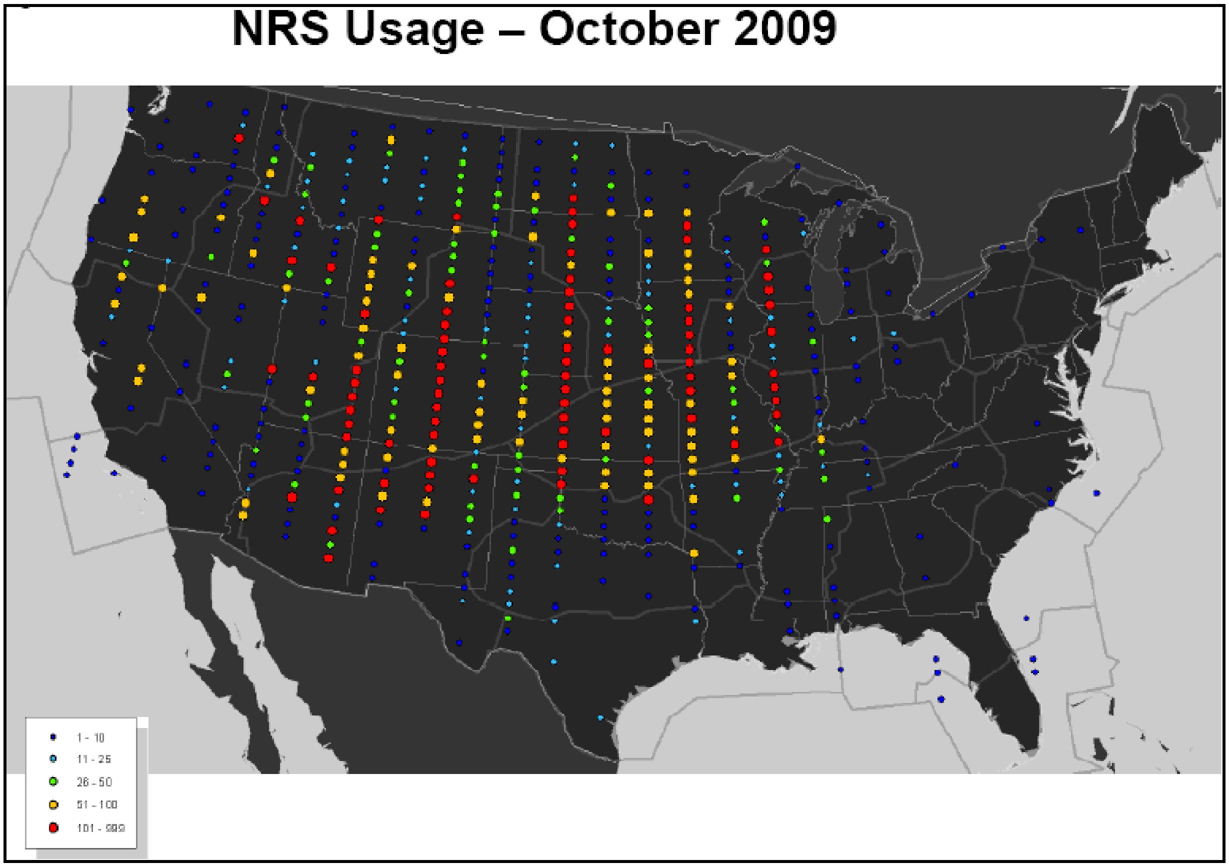

Figure 8. NRS waypoint use in flight plans during October 2009. Dark blue dots signify waypoints that appeared least often in flight plans during the month (1-10 times); red dots signify waypoints that appeared most often in flight plans during the month (101- 999 times). (Courtesy of Lee Brown, MITRE CAASD).

4.3.1 Aircraft Operator Usage – Flight Planning

In our research we conducted interviews with pilots, dispatchers, and managers at the top three air carriers who use NRS waypoints (see Table 2), as well as those same groups at another air carrier who currently makes minimal use of NRS waypoints but plans to increase their usage in the future. All of those interviewed reported that they take a strategic approach to NRS waypoint usage and employ them flight plans to save fuel, time, or both. One carrier files over 7,000 flight plans each month that contain at least one NRS waypoint—many contain two NRS waypoints or more—and estimates their cost savings to be considerable. Another relatively heavy user of NRS waypoints reported that in addition to the strategic use of NRS waypoints during flight planning, their dispatchers use them tactically to generate new weather avoidance routes, sent to their crews via the Aircraft Communications Addressing and Reporting System (ACARS), when convective weather develops along an aircraft's route of flight.

1. American Airlines
2. Skywest Airlines
3. UPS Airlines
4. Air Canada
5. Sun Country
6. Alaska Airlines
7. Fed Ex
8. Frontier Airlines
9. British Airways
10. Northwest Airlines

Table 2. Top ten operators filing NRS waypoints in flight plans (Courtesy MITRE CAASD).

4.3.2 Aircraft Operator Usage – Flight Crew Member

In our research we found that flight crew member usage of NRS waypoints is exclusively limited to those NRS waypoints that appear in their flight plans. Although they might request direct routing to an NRS waypoint to save time or fuel, they would never request diversion to an NRS waypoint if it didn't already appear in their flight plan. Pilots reported that they never request diversion to a non-flight plan NRS waypoint to shorten their route, deviate around weather or SUA, or when dealing with an abnormal or emergency situation aboard the aircraft. Thus, they are not used tactically by pilots during flight as had been hoped by those who developed the NRS waypoint system. Reasons why they are not used in such a tactical manner are primarily related to MFD display and FMS database issues discussed later.

There was some question about the experience of pilots who fly for international carriers who have chosen to use NRS waypoints when flying within the continental United States. Through telephone interviews with two pilots from different international carriers listed in Table 2, we discovered that their knowledge and use of NRS waypoints and the grid differed very little from that of pilots we spoke to at domestic air carriers.

4.3.3 Non-Usage of NRS Waypoints - Aircraft Operators

Just as we conducted interviews at air carriers who use NRS waypoints, we also spoke to individuals representing one major US air carrier and one fractional operation who have made the considered decision not to use NRS waypoints.

The individual we spoke to from the major US air carrier stated that his airline does not incorporate NRS waypoints into their flight operations essentially because of database problems. They operate a large mixed fleet airline and they found there were too many issues to overcome related to operating so many different FMS systems, some with databases that were already completely full. However, since many of their older non-NRS capable fleet is now in storage, the airline is still open to the idea of someday utilizing this navigational tool when they acquire newer aircraft. They are not opposed to the NRS waypoint concept or current design.

The individual we interviewed from the fractional ownership operation stated that they choose not to use NRS waypoints primarily because they do not fit into their operational model. Part of their operational focus is to achieve predictability for their customers. They want to file routes that they know they will be granted so they will be able to tell their owners the exact duration of a flight. (They keep a current database of routes and re-routes that are commonly received.) They perceive however, that ATC is often unwilling to accept NRS waypoints and had often received re-routes because their flight plans with NRS waypoints had been rejected. Therefore, even if a traditional RNAV route takes a longer flight time and burns more fuel, as compared to a route with NRS waypoints, they prefer the predictable route and a more exact and predictable arrival time.

4.3.4 Air Traffic Control Usage – ARTCC

Since NRS waypoints are currently only used at higher altitudes, our research regarding ATC utilization was focused on the enroute portion of air traffic control. There is a significant amount of aircraft operator NRS waypoint usage in the western third of the United States (see Figure 8) so we interviewed Center controllers, supervisors, and managers who work in this area.

The overwhelming consensus from the controllers and managers we interviewed was that their usage of this system was very light. They all agreed that they understand the naming convention and grid structure but their inability to view the grid on their radar scopes is a severe hindrance to their utilization of this resource. Through our research we found that Center controllers tend to not utilize NRS waypoints unless they appear on the flight plan for a particular aircraft. One ARTCC we spoke with estimates that 10-15% of the total flights that pass through their airspace have flight plans comprised of at least one NRS waypoint. They allow these flights to continue as planned on NRS routing whenever possible.

The individuals we interviewed stated that if they do not see an NRS waypoint on an aircraft's flight plan they make the assumption that the aircraft is not capable of or interested in using them. Controllers stated that aircraft equipment suffixes (/E /F /G /R etc.) do not provide sufficient information as to whether or not an aircraft is able to use NRS waypoints. However, even if the equipment suffix was sufficient to make this determination, the controllers are aware that some aircraft have FMS database limitations and reported that they would have to ask a flight crew if they were able to navigate to a specific NRS waypoint not on their flight plan. If an aircraft needs to be diverted from its filed route, the controllers we interviewed stated they would choose a VOR or a traditional RNAV fix such as an intersection, rather than an NRS waypoint.

Those we interviewed described a willingness to offer a short cut by clearing an aircraft to a NRS waypoint further down-line in their flight plan if the waypoint was located in that controller's or Center's airspace. They were less comfortable clearing an aircraft to an NRS waypoint outside of their airspace largely because of their possible lack of knowledge about its exact location.

The placement of NRS waypoints around special use airspace (SUA) has been beneficial in reducing controller workload when needing to vector aircraft around these areas. NRS waypoints that are close to the borders, and especially the corners, of SUA serve as helpful navigation points for keeping deviation time to a minimum. In these cases, the controllers we spoke with are generally quite familiar with the NRS waypoints that are close to these boundaries and make good use of them when diverting aircraft.

NRS waypoints could also be of potential use for creating alternate routes in the event that critical distance measuring equipment (DME) associated with existing ground navigation aids (navaids) becomes unavailable. Critical DMEs are used to define many RNAV routes and when they become inoperable for some reason, the RNAV route associated with them can no longer be used. NRS waypoints, which do not currently depend upon DMEs, could be used for construction of an alternate RNAV route. None of the air traffic controllers, supervisors, or managers we interviewed mentioned using NRS waypoints for such a purpose. This is likely because of several issues which limit their use in such a tactical way, described later.

4.3.5 Air Traffic Control Usage – FAA Command Center

The Air Traffic Control System Command Center (ATCSCC) utilizes a number of pre-planned routes across the country in the event that diversions are needed due to weather or equipage outages. Pre-planned routes are also developed to facilitate heavy traffic flow to various holiday destinations, sporting events (e.g., the Super Bowl) and for other similar occasions. These "Play Book" Routes (2009) are reviewed and updated on a regular basis throughout the year and are published in the ATCSCC National Playbook. Figures 9 and 10 below provide examples of some of these routes that were available from October 22, 2009 to December 16, 2009.

CAN 7 EAST

Facilities Included: ZBW/CZU/CZY/ZMP/ZLC/ZDV/ZSE/ZOA/ZLA

ROUTE

ORIGIN	FILTERS	ROUTE	REMARKS
ZMP		MSP HYR SAW SSM YYB POLTY BUGSY	
ZSE		MLP J36 FAR J140 SSM YYB POLTY BUGSY	
ZLC		BOY J32 CZI J82 RAP J158 ABR FAR J140 SSM YYB POLTY BUGSY	PRIMARY ROUTE
ZLC		EKR MBW RAP J158 ABR FAR J140 SSM YYB POLTY BUGSY	SOUTH OPTION: SEQUENCE WITH ZLA TRAFFIC
ZDV		RAP ABR FAR J140 SSM YYB POLTY BUGSY	
ZOA		SAC J32 CZI J82 RAP J158 ABR FAR J140 SSM YYB POLTY BUGSY	
ZLA		BCE J100 EKR MBW RAP J158 ABR FAR J140 SSM YYB POLTY BUGSY	

DESTINATION ROUTE

DESTINATION	ROUTE	REMARKS
ISP	BUGSY J570 ALB PONEE2	
MMU	BUGSY J570 ALB V489 COATE	
TEB	BUGSY J570 ALB V489 COATE	
PWM	BUGSY NEETS	
ALB	BUGSY	
MHT	BUGSY CON	
BTV	BUGSY	
BDL	BUGSY J570 ALB V130 STELA	
PVD	BUGSY J570 ALB TEDDY3	
HPN	BUGSY ALB VALRE3	
LGA	BUGSY J570 ALB IGN V157 HAARP	
EWR	BUGSY HANAA ALB V213 SAX	
JFK	BUGSY J570 ALB IGN IGN8	

Figure 9. CAN 7 East national playbook routes (ATCSCC, 2009, pg. 516-517).

GRAPHIC: CAN 7 EAST

Figure 10. Graphic depiction of CAN 7 East national playbook routes (ATCSCC, 2009, pg. 518).

To enhance and augment current Play Book routes, in early April 2010, RNAV Wind Route options will be implemented, though initially just for Newark, John F. Kennedy, Teterboro, and LaGuardia airports (see Figure 12). Many of these RNAV Wind Routes will be constructed using NRS Waypoints. For example, “KK48K KI51M KI57O KI63Q KC66S DORET SLT FQM” is one possible Wind Route under current development and review going eastbound through Indianapolis and Cleveland ARTCC airspace into Newark Liberty International Airport (EWR). Note that the first five waypoints in the route are all NRS waypoints but that the entire route is made up of a combination of NRS waypoints and traditionally named waypoints and navaids. It is expected that RNAV Wind Routes and NRS waypoints will improve upon current Wind Route options by providing greater flexibility and reduced congestion at choke points going into high density airspace through the use of parallel tracks.

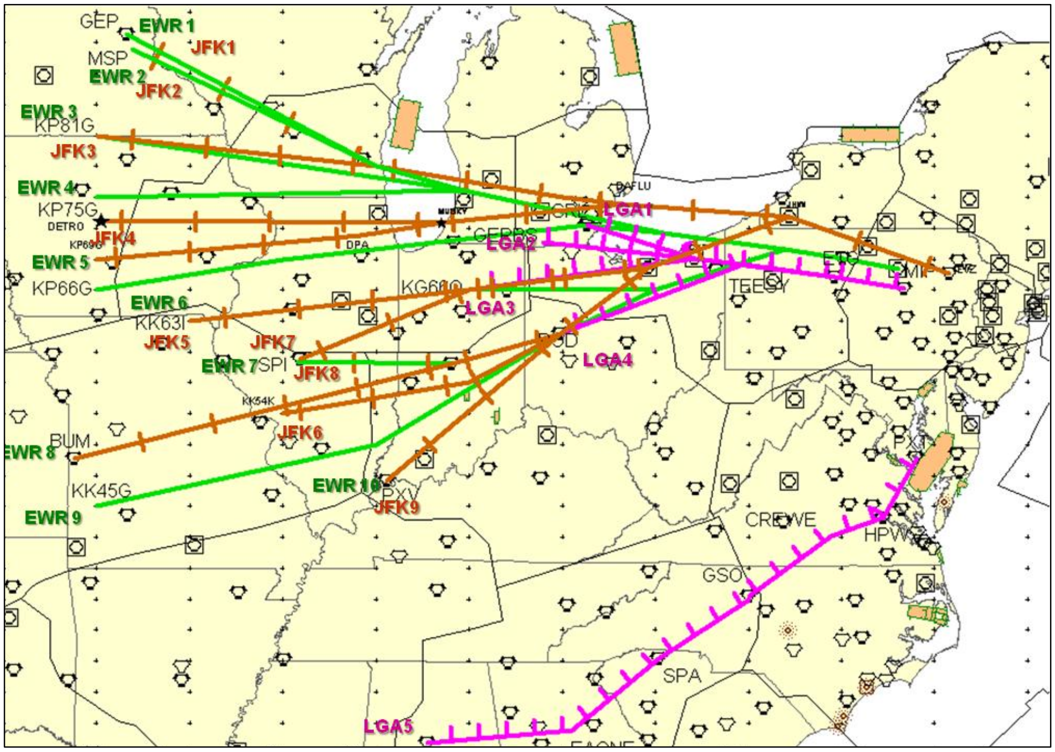

Figure 11. RNAV wind route options for the national playbook, October 2009 (Hannigan, 2009a).

4.3.6 Non-Usage of NRS Waypoints – Air Traffic Controllers

Although the NRS waypoint grid overlays the entire continental United States, very few waypoints to the east of the Mississippi River are currently utilized by ATC or aircraft operators (see Figure 8). Airspace congestion in the eastern third of the US, particularly along the northeast corridor, does not generally allow user-preferred trajectories but rather preferential routing based on traffic flow to the major east coast cities. Additionally, as shown earlier in Figure 1, there is a much greater density of ground-based navigation aids (and named waypoints) in this area generally allowing sufficient flexibility in both route planning and diversions.

4.4 Positive and Negative Aspects of NRS Waypoint Nomenclature and Use

Through our review of pertinent literature, review of incident data, and interviews at airlines and at air traffic control centers, we obtained what we believe is a relatively very clear picture regarding issues faced by those using NRS waypoints. The sections below explore the advantages of NRS waypoints that we discovered through this study (Positive Aspects) as well as the limitations and human factors issues associated with them (Negative Aspects).

4.4.1 Positive Aspects

As mentioned earlier, the studies conducted by MITRE CAASD prior to the deployment of NRS waypoints (Boetig, et al., 2004; Borowski, et al., 2004; Domino, et al., 2003; Domino, et al., 2004) identified some human factors issues of potential concern but also found that pilots and controllers alike held relatively positive attitudes with regard to their nomenclature and potential for use.

As in these pre-deployment studies, we found that with sufficient information or training, those we interviewed understood the intent and structure of both NRS waypoint names and the NRS grid structure. Pilots and controllers tend to think of NRS waypoints in the same ways in which they think of traditionally named waypoints when seeing them on a flight plan and pilots do not believe they contribute to any particular CRM issues on the flight deck or require any changes to pilot flying and pilot monitoring roles and responsibilities. Dispatchers, in particular, agreed that NRS waypoints provide greater flexibility in route planning, especially in the western portion of the US where fewer ground based navigation aids exist. Despite these positive aspects, a number of advantages of the navigation reference system expected by Boetig and Timmerman (2003) and others have not been realized, at least not yet.

4.4.2 Negative Aspects

4.4.2.1 Communication and Waypoint Nomenclature Issues for Flight Crews & Air Traffic Controllers

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). Whereas a named RNAV waypoint is typically a pronounceable one-, two-, or three-syllable word, each character in NRS waypoint names generally must be verbalized separately using the phonetic alphabet and numbers. The exception to this is that the two numerals denoting the latitude line may 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 ASRS, ASAP, and ATQA databases 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 waypoints begin to be used tactically by pilots and controllers with requests or assignments to divert to non-flight plan NRS waypoints communicated via voice over the radio.

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 now since NRS waypoints have not been adopted outside of the United States.

As discussed earlier, the second letter in NRS waypoint names are the single letter identifiers for the ARTCC in which the waypoint is located (see Table 1). 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 enroute charts despite knowing in which Center's airspace the waypoint was located and despite their having a good understanding the grid structure. (These difficulties went beyond issues in reading the waypoints on the charts, described later).

Interviews with pilots confirmed our suspicions that ARTCC identifiers are not commonly known to pilots and provide little to no geographical knowledge to them. Pilots also suggested that because ARTCC boundaries are irregularly shaped and are generally unknown to flight crew members, including an ARTCC identifier as part of an NRS waypoint name is of little utility. (Center airspace boundaries are indicated on enroute 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."

4.4.2.2 Cognitive Limitations - Flight Crews & Air Traffic Controllers

When humans are presented with information that will be immediately used, we hold this information in working memory. It is well understood that there are significant limitations to working memory capacity and this capacity 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 drop out to make room for new information that comes in.

Working memory limitations have important significance with regard to the nomenclature of NRS waypoints. 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 dropped 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: <u>Delta</u> – <u>fifty-four</u> – <u>Uniform</u>. It comprises five units of information when each character is remembered and the numerals are treated as two separate numbers, thus: <u>Kilo</u> – <u>Delta</u> – <u>Five</u> – <u>Four</u> – <u>Uniform</u>. 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 our working memory capacity. Remembering two NRS waypoints in a spoken clearance could easily exceed its 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, 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.

4.4.2.3 Waypoint Geographical Knowledge Issues for Flight Crews

For the pilots that we interviewed, the most common two issues we heard related to geographical knowledge were 1) the inability to easily display non-flight plan NRS waypoints on the MFD to more easily determine their location, and 2) NRS waypoint nomenclature (ARTCC identifiers not known, latitude numbers not matching real latitudes, using letters to signify longitude), both of which have been described earlier.

The fact that current FMSs do not allow the display of non-flight plan or specifically selected NRS waypoints on the aircraft's MFD poses as a significant hindrance to their tactical utilization by pilots. Pilots we interviewed told us that when a re-route or deviation is required for weather they are likely to choose one of two options: 1) look out the window or at the cockpit radar display and ask ATC for a specific vector around the weather or, 2) choose an appropriate visible waypoint on their MFD, which is overlaid on the weather radar display, and then request direct routing to that waypoint from ATC. Currently, identifying a NRS waypoint that is well-located geographically for such a diversion requires that the pilot mentally transpose the weather radar picture on the MFD display to a paper enroute chart. To do this would clearly involve a significant increase in pilot workload, and would likely be an inaccurate estimate.

With regard to the second issue (NRS waypoint nomenclature and geographical knowledge), as described earlier, although ARTCC boundaries are marked on enroute charts, crews do not tend to keep paper charts readily available. Navigation displays, which have largely taken the place of paper charts in normal operations, do not depict ARTCC sector boundaries. Thus, pilots do not tend to keep careful track of where they are in relation to ARTCC boundaries while enroute and waypoints that contain ARTCC abbreviations are of little help to them in determining the geographic location of the waypoint. It is possible that the lack of pilot knowledge of ARTCC boundaries is aggravated by the fact that commonly used weather reports such as SIGMETS and AIRMETS, are given based on relation to ground based navaids. Some operators even provide their pilots with a map showing these navaids to help pilots better understand the location of significant weather along their route of flight. We were unable to find such a "significant weather map" provided to flight crews which also depicted NRS waypoint locations and ARTCC boundaries.

4.4.2.4 Waypoint Geographical Knowledge Issues for Air Traffic Controllers

The most common NRS waypoint geographical knowledge issue for the ATC employees we interviewed is the lack of NRS waypoint depiction on controller radar scopes. They stated that because of this, their ability to understand or "visualize" the location of NRS waypoints in flight plans or NRS waypoint requests, even a request to go direct to an NRS waypoint already in an aircraft's flight plan, is severely hampered. For example, controllers reported that visualization of where a NRS waypoint in a re-route request is located and the re-route's impact on traffic flow, conflict and airspace limitations can be quite difficult. This is particularly the case when the requested waypoint is outside of the controller's sector.

This impediment to geographical waypoint awareness is the primary reason that the air traffic controllers we interviewed choose not to use NRS waypoints tactically when issuing a diversion (i.e., clear an aircraft to an NRS waypoint that is not already on the aircraft's flight plan). The time it takes to utilize alternate resources to locate NRS waypoints, such as the URET system or charts depicted above their consoles can be rather lengthy and, as stated earlier, information from these alternate sources must then often be mentally transposed to the controllers radar in order for them to be assured of all the traffic management consequences of issuing such a diversion.

4.4.2.5 Chart Readability and Use Issues for Flight Crews

Readability of NRS waypoints on both the Jeppesen and NACO charts, printed in black and light green type, respectively (see Figure 4), was rated as quite low by the pilots we interviewed. The NRS waypoints depicted on the NACO chart are particularly faint and difficult to identify and read. Chart clutter is another problem that contributes to the difficulty of finding and reading NRS waypoints on high altitude enroute charts. Examination of both types of charts over several sections of the United States revealed significant clutter and in some cases NRS waypoints are essentially buried among other data. This problem is most prevalent in the northeastern US due to a high concentration of navigational symbology and airway congestion.

Lines of latitude and longitude are drawn on enroute charts and to some degree, these lines do make it easier to identify NRS waypoints, which appear where some of these lines intersect. On both Jeppesen and NACO charts the lines are labeled with their degree (e.g., N43^{o}, W76^{o}) at various points along the line. Because NRS waypoints do not incorporate the actual latitude or longitude degree in their names, the latitude and longitude labels on enroute charts do not assist pilots in locating a specific NRS waypoint unless the pilot is aware of the NRS latitude numbers or longitude letter that correspond to the actual latitude or longitude degree.

Because the pilot and dispatchers we interviewed found specific NRS waypoints difficult to locate and read on these charts when sitting at a table in a room with good lighting, it is reasonable to predict that readability and utility of either chart shown in Figure 4 would be significantly decreased on a dark flight deck or with high workload and turbulence as additional factors.

4.4.2.6 Displays Issues and FMS Concerns for Flight Crews

As mentioned earlier, we found that the primary reason that pilots do not use non-flight planned NRS waypoints tactically is due to limitations in displaying NRS waypoints on their multi-functional displays (MFDs). When a specific NRS waypoint is selected from the FMS database and entered, it is displayed on the MFD since it is part of the programmed route that is now active. However, when pilots display navigational fixes on the MFD more generally, such as when looking for one to divert to, the NRS waypoint grid is not displayed with the rest of them. Thus, as described earlier, any attempt to utilize a NRS waypoint for deviation requires the retrieval of a paper enroute chart, finding the aircraft's current location and route, and then determining which NRS waypoint on the chart would work best for the deviation required.

A factor which further complicates using NRS waypoints tactically for diversions is that some FMS systems will not display NRS waypoints selected from the FMS database unless the navigation display range is set at 60 nm or less. Diversion planning is typically conducted as far out as is practicable to allow a diversion as close to the original flight path as possible. Hence, the MFD display range during diversion planning is often set at far greater than 60 nm.

Another very significant factor affecting the utility of NRS waypoints by flight crews concerns FMS database limitations. FMS databases have limited capacity and many operators are unable to load all the current 1600 NRS waypoints. Figure 12 depicts the NRS waypoints that have been removed from one operator's FMS databases (shaded over in green) in an effort to accommodate capacity restrictions. Although this responds to the database problem, it also creates an additional burden for pilots who would now have to check if their database includes a particular NRS waypoint that might be offered by ATC. The issue of database limitations will continue to be a concern with the proliferation of RNAV procedures that possess numerous new waypoints making free database memory even more scarce.

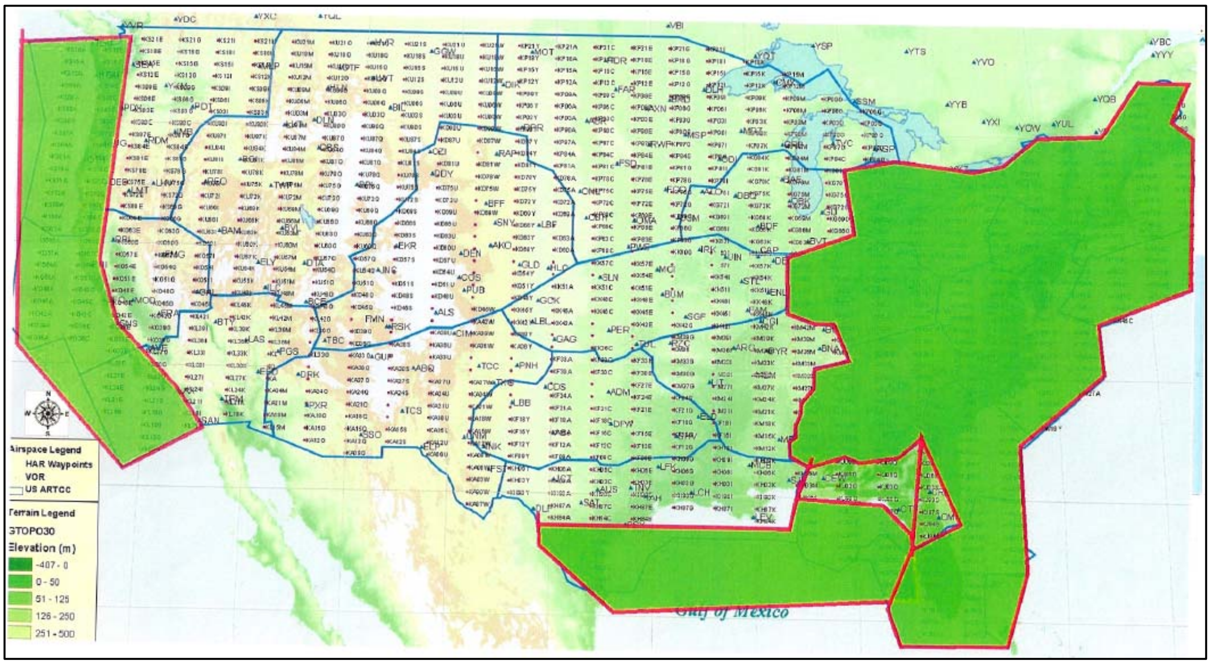

Figure 12. NRS waypoints deleted in the aircraft FMS databases of one domestic air carrier (shaded over in green). (Courtesy of the Participating Operator).

4.4.2.7 Displays Issues for Air Traffic Controllers

As already discussed, air traffic controllers are not able to overlay the NRS waypoint grid on their radar scopes. This poses numerous problems and, as with the similar problem for flight crews, likely contributes to the lower than expected NRS waypoint use. Other waypoints are depicted on their scope and not only support awareness of their location but the DSR system can also determine bearing and distance from these waypoints for any aircraft target on their scope. This ability enhances controller "new course" situational awareness prior to clearing an aircraft to a new fix.

When an aircraft is on a route that contains NRS waypoints in the controller's airspace, the conspicuity of the NRS waypoint for the controller is minimal at best. The controllers we spoke to reported that typically the first indication of such a waypoint is a change in the course-line (when course-lines are selected for display). If the "show course-line" option is not selected or the bearing change at the waypoint is small, sometimes it is not even evident that a NRS waypoint is being used for navigation.

4.4.2.8 Data Entry Difficulties for Flight Crews

According to the pilots we interviewed, issues with regard to NRS waypoint entry into a FMS do not appear to be significantly different than traditional waypoint entry issues. As with named waypoints, incorrect or false NRS waypoint entry is a concern. Occasionally, an incorrectly input NRS waypoint will be rejected by the FMS suggesting to the pilot that it has been mistyped.[3] It is the structure of NRS waypoint nomenclature that allows for the identification of the incorrect entry of some of its characters. For example, the first letter in an NRS waypoint name is always "K," so if the first two letters in an NRS waypoint are transposed during entry, the system should not accept it. The possibility of transposing the two numerals that signify the line of latitude in the NRS waypoint name has specifically been identified as a concern, (i.e. KD54U instead of KD45U; FAA, no date-b). Although we did not find this specific error through our pilot interviews or review of ASRS or ASAP databases, we believe that they are still probably at great risk for this type of error since they are both numerals and many combinations are possible.

The structure of NRS waypoint nomenclature also facilitates the identification of numerals and letters that have been confused with each other such as when the letter "O" is input for the number zero (0) or when the letter 'I" is similarly confused with the number one (1). As with named waypoints, however, the FMS will not reject NRS waypoint names which exist in the database but are not the NRS waypoints actually desired by the flight crew.

> "We were cruising at FL390 when ATC asked us to clarify what our next waypoint was. We told them KP84G. We realized then that we had been proceeding direct KP84G instead of direct KP84A, which was our clearance. ATC then asked us if we would like to go direct DSM or TTH, we chose

[3] It is also possible however, that a waypoint which has been rejected has been correctly typed but does not exist within that aircraft's FMS database.

direct TTH. At the time we were cleared direct TTH we were approx 25 to 30 miles north of our route. We had mistakenly programmed KP84G in the FMC instead of KP84A. Even though we had discussed the possibility of this problem a couple of flights earlier and checked our route that day, this was missed. The NRP's[4] are just too easy to transpose and not intuitive to a location." (Airline ASAP Report)

> During preflight the PDC alerted us to a change in the filed route commencing with J89 direct BVT. The Captain and I discussed the change and it's entry into the FMC. However, I then entered the remaining NRP points in error. They were KG78K-KP90G-KP09A. Due to some distraction during entry I entered, after KG78K-KP90A transposing numbers from one waypoint and adding the last alpha character from the last waypoint and omitting a point. This resulted in about a 15 degree turn off course that was queried by ATC after about 3 minutes. We then recognized the error and omission and were cleared back to the proper course with no apparent conflict noted by ATC. I believe one contributing factor was the similarity between the two NRP points KP90G and KP09A in close succession. (Airline ASAP Report)

Flight crews at almost all of the air carriers we visited reported that the quality of the print on their flight plan and dispatch papers also has contributed to some confusion and data entry errors with regard to NRS waypoint names. It can be quite difficult to distinguish between "C," "G," "O," and "Q," in particular, on release packages that have been printed with dot matrix printers.

The structure and design of the flight management system's multifunction control display unit (MCDU) appears to also contribute to some of the data entry issues experienced by the pilots we spoke to. Figure 13 shows one model of a FMS MCDU. Examination of this model, which is similar to many types of FMS MCDUs, reveals that 1) the numerical keypad is not the same as that found on many devices, such as computers and calculators, but instead matches the numerical layout of a telephone keypad, and 2) the keypad presents letters in alphabetical order rather than in the QWERTY layout prevalent on typewriter and computer keyboards. It is possible that these differences in presentation can increase the amount of time it takes for pilots to locate a desired letter or number and contribute to data entry errors.

Additionally, unlike traditional waypoints and navaids, NRS waypoint names are comprised of both letters and numbers. Thus, pilots must shift back and forth between both sections of the keypad when entering in a NRS waypoint, adding to the time it takes for data entry.

Although Domino, et al. (2004) did not find that their corporate pilot subjects made any NRS waypoint data entry errors, the fact that their assessment was performed using a laptop computer in a quiet room limits the generalizability of their findings to actual airline operations on the flight deck.

[4] Some individuals we interviewed referred to NRS waypoints as NRP or HAR waypoints.

Figure 13. FMS MCDU (Modena, NA)

4.4.2.9 Data Entry Difficulties for Air Traffic Controllers

The NRS waypoint entry difficulties identified by the air traffic controllers we spoke to were very similar to those identified by pilots:

- The transposition of characters within a NRS waypoint name is a concern although the DSR systems will not accept some types of incorrectly input NRS waypoints (i.e., those that do not conform to the structure for NRS waypoint names)

- Layout of numbers on the DSR keyboard do not conform with the standard layout of numbers on computer keyboards or calculators and contributes to errors

- Shifting back and forth between the letter and numerical sections of their DSR keypad is cumbersome and contributes to errors

We did not discover any ASRS and ATQA reports that described data entry errors with regard to NRS waypoints and are unaware of any data indicating the frequency with which these types of errors occur in the ATC environment.

4.4.2.10 Paper Strip Marking Issues for Air Traffic Controllers

Because of the automation and displays currently available to most Center controllers, the use of paper flight progress strips has largely been phased out. The ARTCC we visited retained some of the equipment for processing paper flight strips however, in the event that it would be needed due to an equipment outage. We did not query the controllers we spoke to with regard to NRS waypoint issues relative to using paper strips since they no longer use them in daily operations.

In a pre-deployment study, Domino, et al. (2003) found that controllers reported that marking NRS waypoints on paper strips was more difficult as compared to marking named waypoints (possibly due to unfamiliarity with NRS waypoint nomenclature), and that careful reading of strip data was necessary because of the similarity of NRS waypoint names. It is likely that the second finding, in particular, would still be an issue if controllers were required to revert to using paper flight progress strips to manage flights.

4.4.2.11 Workload Concerns for Flight Crews

Effective cockpit resource management (CRM) is considered the cornerstone for any safe flight operation. The pilots that we interviewed reported that as a part of CRM, they are required to observe or check a co-pilot’s data entry into the FMS and that both pilots must confirm that all data have been entered correctly. This practice is true for all types of data and the pilots we spoke to agreed that the NRS waypoint usage has had no perceptible change in their FMS data entry procedures or techniques or in their CRM more generally.

The pilots we interviewed also reported that the ways in which they currently use NRS waypoints (i.e., strategically, as a part of a flight plan, but not tactically while enroute) do not add in any significant ways to their workload on the flight deck. In fact, the limitations they have placed on how they use NRS waypoints are to minimize the amount of workload that might be related to them. For example, several indicated that if they tried to use them tactically, workload could become quite high due to increased frequency congestion, human working memory limitations, lack of geographical knowledge about waypoint locations, lack of waypoint MFD display capabilities, paper chart readability issues, and the increased potential for waypoint entry errors.

In pre-NRS deployment studies, several workload tasks were evaluated with airline pilots (Boetig, et al., 2004) and corporate pilots (Domino, et al., 2004) including: 1) locating NRS waypoints on a high altitude enroute chart, 2) constructing a flight plan that includes NRS waypoints in a desktop computer simulation of a FMS, and 3) altering a flight plan after “takeoff” to fly direct to a flight plan NRS waypoint. The results of their research were generally favorable for the use of NRS waypoints during the relatively low workload enroute phase of flight. Overall, their subjects found these tasks to be relatively easy and spoke favorably about NRS waypoints during the post-test interviews.

In contrast, the pilots that we interviewed generally expressed fairly negative opinions about NRS waypoints, waypoint use, and waypoint nomenclature though they agreed that entering waypoints into a FMS flight plans and later choosing to fly "Direct To" an NRS waypoint included in the flight plan were not difficult tasks.

4.4.2.12 Workload Concerns for Air Traffic Controllers

In our interviews with air traffic control managers, supervisors, and controllers we found the desire and enthusiasm to use NRS waypoints to be quite low. A number of issues described earlier contribute to this lack of interest: NRS waypoints cannot be displayed on their radar scopes, controllers are unable to determine bearing and distance between target aircraft and NRS waypoints on their radar, and they have difficulty visualizing the location of NRS waypoints within their sectors and visualizing an aircraft's route should the flight crew wish to divert to an NRS waypoint outside of their sector. A few controllers also indicated that having to shift back and forth between alpha and numeric characters on the DSR keyboard to enter NRS waypoint names was cumbersome and that they had to be careful not to make a data entry error because the numeric portion was laid out differently than number keypads on computer keyboards.

The controllers reported that their inability to display the location of NRS waypoints on their scopes causes a large increase in their workload, particularly during high traffic counts with mixed equipage aircraft; and some controllers reported that when traffic counts get high, NRS waypoints are the "first thing to go" in order to keep workload manageable. They prefer pilot generated direct routing requests to traditional RNAV waypoints or navaids, rather than NRS waypoints, as far fewer steps are required to determine their suitability. The managers, supervisors, and controllers we interviewed did not believe that NRS waypoints had many strategic or tactical advantages with the exception of those surrounding SUA which provide greater options for diversions.

4.4.2.13 Other NextGen Operational Concerns

Through the course of this study, we have identified several other issues pertaining to NRS waypoint usage, particularly in the upcoming years as increasing numbers of NextGen technologies become available and procedures are implemented:

1. NextGen airspace redesign will affect ARTCC boundaries and quite possibly alter the current number of facilities. There is also some discussion of implementing dynamic sector, and possibly even Center, airspace boundaries (i.e., boundaries that change in response to traffic counts). Both of these initiatives have implications for the current NRS waypoint naming convention.

2. A report by the General Accounting Office (GAO; 2009), warns that at the current level of satellite production and deployment, the complete global positioning satellite (GPS) constellation could drop to or below 21 satellites rendering the system significantly unreliable for position determination. They predict that during the fiscal years 2018 thru

2020, the chance for this occurrence is between 20 and 50%. Although this decrease may be more detrimental for terrestrial GPS users, flight operations could be significantly affected and should be considered. Navigation to RNAV waypoints, including NRS waypoints, is dependent upon GPS systems in many aircraft.

3. DME/DME navigation is a back-up procedure which could be used in the event that GPS is unavailable. In some cases, new ground infrastructure may be required so that critical DMEs to support area navigation and NRS waypoint use are available.

4. The development of the NRS waypoint grid has always been seen as a temporary aid to RNAV navigation until data link communications are fully operational and used by the majority of commercial aircraft; currently expected sometime after 2018 (FAA, 2010). At that time, it is anticipated that using advanced technology, such as a mouse or touch screen, the full latitude and longitude coordinates for any point in space could be easily identified and transmitted between flight crews and ATC. In this vision of the future, manual data entry of the coordinates will not be required and a NRS waypoint grid will be too confining and no longer necessary. It has been suggested that some sort of back-up plan should be in place, such as retaining the grid, if there is a disruption in datacomm capability.

4.5 Other Navigational Grid Systems in Use

We gathered information about other navigational grid systems in use by the military (GARS; Wickman, no date) and in the Gulf of Mexico (Nault, no date) to determine if approaches used by these systems might address some of the limitations identified with the NRS. We discovered that the two systems reviewed use a grid to identify a two- or three-dimensional area to which an aircraft is directed. The aircraft may fly anywhere within that area as it progresses to the next area to which it has been cleared (something akin to being granted a block altitude). This is quite different from the NRS system in which aircraft are cleared to the specific points which make up the grid intersections. In other words, the NRS waypoint system is concerned with the corners of the box, the other grid systems are concerned with the space that is inside of the box. Because of these substantial differences, it is unlikely that the approaches of these other grid systems have current utility for IFR navigation within the NAS.

5.0 RECOMMENDATIONS

Through the course of this study we discovered that although most individuals we spoke to understood and appreciated the intended advantages of NRS waypoints and the grid, they felt that a number of issues impeded realization of those advantages.

Some of the most significant limitations with regard to NRS waypoints and the grid as they are currently named and deployed are:

- Inability of both pilots and air traffic controllers to display NRS waypoints on their primary workstation displays (i.e., navigation displays, DSR radar scopes) in ways which support their greatest use, particularly tactically for requesting or assigning re-routes
- Lack of sufficient information available to controllers to determine which aircraft are capable of using NRS waypoints
- FMS database limitations which restrict the number of NRS waypoints that can be included and hence, displayed on cockpit displays
- Several issues related to the specific nomenclature of NRS waypoints: confusing, do not provide or support “geographic knowledge” as originally intended, easily confused with each other which contributes to data entry errors, impose increased cognitive demands,
- Issues related to their depiction on paper charts: hard to read, contribute to chart clutter and difficult to locate within chart clutter, difficult to locate a specific waypoint even when chart clutter is not an issue
- Lack of sufficient certification and operational guidance with regard to NRS waypoint use, and
- Apparent lack of sufficient knowledge about NRS waypoints and the grid by some pilots and controllers

If these limitations are not addressed and NRS waypoints were to be used tactically for diversions to NRS waypoints not originally included in flight plans, there would also be:

- Significantly increased workload for both pilots and controllers
- Significantly increased radio frequency congestion, and
- A likely increase in data entry errors for both pilots and controllers

Despite the limitations that exist even as they are currently employed, users of NRS waypoints have identified some benefits:

- Provide increased flexibility in route planning (air carrier flight planners/dispatchers)
- Provide increased flexibility in developing wind routes (ATCSCC)
- Provide increased flexibility in issuing route changes around SUA (air traffic controllers)

The planned second phase of this study (beginning April 2010) will be devoted to the generation of specific recommendations to address many of the limitations and issues identified and described above and throughout this report. The identification of workable solutions to the issues identified is required if they are to be used as described in the National Airspace

Procedures Plan (Brian Holguin, personal communication, March 8, 2010) and in the NextGen air traffic management system, more generally (RTCA, 2009).

To ensure the greatest utility of proposed solutions,

- the findings in this report should be used as the baseline or starting point for the task of solution generation

- individuals representing all sectors of the NRS waypoint user community need to be involved in developing potential solutions

- 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,
    - feasibility of retrofits or upgrades to FMS and DSR databases and displays,
    - alternate equipment suffixes (/E, /F, /G, R), and
    - the use of automation to convert fix-radial-distance information for NRS waypoint generation, among others

- solutions generated must be evaluated against proposed NextGen airspace changes (e.g., dynamic sector boundaries, generic airspace at high altitudes, etc.), and

- solutions generated should be tested and validated, if possible.

Although human factors issues of an expanded NRS waypoint grid (i.e., below FL180, increased density to 6600 waypoint, possible utilization in the terminal operating environment) are to be examined during Phase 3 of the study, the potential for such an expansion will need to be kept in mind during the solution development portion of Phase 2. Solutions generated during Phase 2 will be of little use if they do not also work under grid expansion, considered during Phase 3.

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APPENDIX 1

Acronyms and Abbreviations

ACARS	Aircraft Communications Addressing and Reporting System
AIRMETS	Airmen's Meteorological Information
ARTCC	Air Route Traffic Control Centers
ASAP	Airline Safety Action Program
ASRS	Aviation Safety Reporting System
ATC	Air Traffic Control
ATCAA	Air Traffic Control Assigned Airspace (avoidance)
ATCSCC	Air Traffic Control System Command Center
ATQA	Air Traffic Quality Assurance
CFR	Code of Federal Regulations
CRM	Cockpit (or Crew) Resource Management
DSR	Display System Replacement
FAA	Federal Aviation Administration
FL	Flight Level
FMS	Flight Management System
GAO	Government Accounting Office
GARS	Global Area Reference System
GPS	Global Positioning System
HAAM	High Altitude Airspace Management Program
HAR	High Altitude Redesign
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
JPDO	Joint Planning and Development Office
MCDU	Multifunction Control Display Unit
MFD	Multi-functional Display
MSL	Mean Sea Level
NACO	National Aeronautical Charting Office
NAS	National Airspace System
navaid	Navigation Aid
NextGen	Next Generation Air Transportation System
nm	Nautical Miles
NRP	National Route Program
NRR	Non-Restrictive Routing
NRS	Navigation Reference System
RNAV	Area Navigation
RTCA	Radio Technical Commission for Aeronautics

SIGMETS	Significant Meteorological Information
SUA	Special Use Airspace
TMU	Traffic Management Unit
UPS	United Parcel Service
URET	User Request Evaluation Tool
VOR	Very high frequency Omni directional Radio Range
ZAB	Albuquerque Center

APPENDIX 2

Database Search Terms

enroute navigation

enroute waypoint (waypt, wpt)

FMS database

HAR

HAR waypoint (waypt, wpt)[6]

K fix (fixes)

K waypoint (waypt, wpt)

National Route Program

NRP

NRP waypoint (waypt, wpt)[7]

Navigation Reference System

NRS

NRS waypoint (waypt, wpt)

RNAV route (rte)

RNAV waypoint (waypt, wpt)

Q Route (Rte)

waypoint (waypt, wpt)

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[6] Because of their association with the HAR program, some individuals refer to NRS waypoints as "HAR waypoints".

[7] Because of their use in the National Route Program, some in the industry refer to NRS waypoints as "NRP waypoints"

APPENDIX 3

Semi-Structured Interview Questions – Air Carriers

RNAV Managers

1. Does your company make use of the NRS system routinely as part of their normal flight planning process? Why (or why not)? If so,
    a. Did this require any significant coordination or interaction with the various air traffic control facilities your company deals with?
    b. If so, why was this coordination necessary?
        i. What were the issues ATC needed to address?
    c. What training program, if any, was required for the dispatchers/flight planners to transition to the use of NRS waypoints?
    d. What training program, if any, was required for the pilots to transition to the use of NRS waypoints?
    e. What training issues, if any, cropped up when you introduced the waypoints?

2. When did you begin using NRS waypoints?

3. How are NRS waypoints used within your company: flight planning only, pilot-requested re-routes, ATC re-routes, tactically to deviate around weather, to take advantage of winds/more direct routing, etc.?

4. Would you consider use within your company to be heavy, moderate, light? Do you see this changing in the future? Why or why not?

5. Do you find the current granularity/density of waypoints sufficient for your use?

6. What is your concept of the NRS system? (Understand the NRS system is laid out in a grid, understand logic behind the nomenclature, etc?)
    a. Do you feel comfortable with the naming convention? Why or why not?

7. To what degree do you see NRS waypoints as being the same or different as named waypoints?

8. How many different fleets/models of aircraft are used by your company?

9. Are there any differences by fleet/model of aircraft in terms of the use of NRS waypoints? If so, why?

10. What advantages / disadvantages do you find from using NRS waypoints?

11. Would you make any modifications to the system? If so, how and why?

FMS Database Managers

1. How many different fleets/models of aircraft are used by your company?

2. Across these different fleets and models, how many different FMS systems are installed?

3. Across these different FMS systems, how many have NRS waypoints in their databases?
    a. What (is) are the memory capacities of these different FMS systems?
        i. Can (it) they handle the full 1600 waypoints currently in use? How about the increase to 6600 waypoints anticipated in the future?
        ii. Does memory capacity limitation affect the level of NRS waypoint usage that you desire?
        iii. Are you dealing with memory storage problems vis a vis the FMS system(s) now? If so, how are you dealing with these problems?

4. Are there any (other) NRS waypoint issues you are aware of? If so, what are they?

Dispatchers / Route Planners

1. Do you find the current granularity/density of waypoints sufficient for your planning purposes?
    a. Do you know how the current granularity affects flight crew tasks on the flight deck as they transition between NRS waypoint NAV and airways NAV?

2. What is your concept of the NRS system? (Understand the NRS system is laid out in a grid, understand logic behind the nomenclature, etc?)
    a. Do you feel comfortable with the naming convention?
        i. What issues, if any, have you experienced with trying to use the naming convention to locate specific waypoint locations?

3. To what degree do you see NRS waypoints as being the same or different as named waypoints?

4. Do you make use of the NRS system for re-routes in flight?
    a. How do you plan the route diversion and determine which waypoints to use?

5. What did your training to utilize NRS waypoints consist of?
    a. What gaps in your training, if any, were revealed to you after working with the NRS system for a while?
    b. What would you change about this training, if anything?
6. Are there issues with FMS equipage from aircraft type to aircraft type with regards to dispatch planning or flight monitoring? If so,
    a. How do you vary your planning based on these equipage issues?

   b. How do these various planning requirements affect planning flexibility, if at all?

7. What advantages / disadvantages do you find from using NRS waypoints?

8. Would you make any modifications to the system? If so, how and why?

Corporate Safety Managers

1. Are you aware of any issues that have been raised within your company with regard to NRS waypoints and their use? If so, what are they?

2. Does your company have a significant event reporting system that is searchable?
   a. Would you run a search using the terms, Waypoint, RNAV, NRS, FMS database, Q-route?

Flight Crews / Check Airmen

1. When did you begin using NRS waypoints?

2. What training program, if any, was required for pilots to transition to the use of NRS waypoints?
   a. What would you change about this training, if anything?

3. How do you use NRS waypoints: flight planning only, pilot-requested re-routes, ATC re-routes, tactically to deviate around weather, to take advantage of winds/more direct routing, etc.

4. Do you find the current granularity/density of waypoints sufficient for your use?

5. Would you consider use within your company to be heavy, moderate, light? Do you see this changing in the future? Why or why not?

6. What is your concept of the NRS system? (Understand the NRS system is laid out in a grid, understand logic behind the nomenclature, etc?)
   a. Do you feel comfortable with the naming convention?
      i. What issues, if any, have you experienced with trying to use the naming convention to locate specific waypoint locations?

7. To what degree do you see NRS waypoints as being the same or different as named waypoints?

8. What keystroke procedures are required to enter NRS waypoints into your FMS?

9. Does your company have any special procedures or policies regarding the use of NRS waypoints? If so, what are they and why?
    a. (Safety, reliability, workload management,) etc.

10. What errors have turned up in crew use of NRS waypoints?
    a. What do you believe the most frequent type of error associated with NRS waypoint usage to be?
    b. What type of error do you believe is the most consequential and why?

11. Are there any Nav Display issues with regard to NRS waypoints? If so,
    a. What are they?
    b. How do they affect your use of NRS waypoints, if at all?

12. What (other) issues have you/flight crews identified regarding using NRS waypoints and how do they affect your use of NRS waypoints, if at all?
    a. ATC familiarity?
    b. Spatial /geographic orientation?
    c. Keypunch / waypoint name entry?
    d. Database limitations?
    e. Workload?
    f. Coordination:
        i. Between flight crewmembers?
        ii. Between the flight and the dispatch center?
        iii. Between the flight and ATC?
    g. Transitions between one NAV system and another? NRS / Airway?
    h. Naming system – learning / orienting?
    i. Clearance readbacks / hearbacks?
    j. Have crews mentioned any added capability or coverage that they would like to see using these waypoints (expansion below FL180, increase to 6600)?

13. What advantages or disadvantages do you find from using NRS waypoints?

14. Would you modify the system in any way? If so, how and why?

Flight Crew Instructors

1. What training program if any was required for the pilots to transition to the use of NRS waypoints?

2. What training issues cropped up when you introduced the waypoints, if any?

3. Do any training issues persist today? If so, what are they?

APPENDIX 4

Semi-Structured Interview Questions – Air Traffic Control

Support Manager Airspace and Procedures, Traffic management Officer, Supervisory Traffic Management Coordinators

1. When did you begin using NRS waypoints?

2. What training program was required for air traffic controllers to transition to the use of NRS waypoints?
    a. What would you change about this training, if any?

3. What is your concept of the NRS system? (Understand the NRS system is laid out in a grid, understand logic behind the nomenclature, etc?)
    a. Do you feel comfortable with the naming convention?
        i. What issues, if any, have you experienced with trying to use the naming convention to locate specific waypoint locations?

4. To what degree do you see NRS waypoints as being the same or different as other named waypoints?

5. How do you use NRS waypoints (Playbook routes, pilot-requested re-routes, ATC re-routes tactically to deviate around weather, to take advantage of winds/more direct routing, etc.)?

6. Are there internal or external policies regarding the use of NRS waypoints? If so, what are they and why?
    a. (Safety, reliability, workload management, etc.).

7. Do you find the current granularity/density of waypoints sufficient for your use?

8. What would you consider your use of NRS waypoints to be heavy, moderate, light? Do you see this changing in the future? Why or why not?

9. What procedures are required to enter NRS waypoints into a flight's clearance?
    a. Are there any issues/problems with regard to this procedure? If so, what are they?

10. What issues or problems have turned up in Air Traffic Controller/Traffic Management Unit use of NRS waypoints? If so,
    a. What do you believe is the most frequent type of ATC issue or problem associated with NRS waypoint usage?
    b. What type of problem related to ATC do you believe is the most consequential and why?

11. What issues or problems have you seen in flight crew use of NRS waypoints?
    a. What do you believe is the most frequent type of issue or problem related to pilot associated with NRS waypoint usage?
    b. What type of problem related to pilots do you believe is the most consequential and why?

12. Are there any issues with displaying NRS waypoints on your scopes/displays? If so,
    a. What are they?
    b. How do these issues affect your use of NRS waypoints, if at all?

13. How do you identify which aircraft are capable of using NRS waypoints?

14. What (other) issues have you identified regarding using NRS waypoints?
    a. Pilot familiarity?
    b. Spatial/geographic orientation?
    c. Keypunch/NRS waypoint name manual entry?
    d. Aircraft database limitations?
    e. Workload?
    f. Coordination:
        i. Between air traffic controllers?
        ii. Between you and the pilots/flights
    g. Transitions between one NAV system and another? NRS/Airway?
    h. Naming system – learning/orienting?
    i. Clearance readbacks/hearbacks?

15. What issues exist, if any, in managing mixed capable aircraft (some are NRS capable, some are not, some can accept a larger number of NRS waypoints than others, etc.)?

16. What advantages or disadvantages do you find from using NRS waypoints?

17. Would you modify the system in any way? If so, how and why?

Air Traffic Controllers/Traffic Management Coordinators

1. What is your concept of the NRS system? (Understand the NRS system is laid out in a grid, understand logic behind the nomenclature, etc.)?
    a. Do you feel comfortable with the naming convention?
        i. What issues, if any, have you experienced with trying to use the naming convention to locate specific waypoint locations?

2. To what degree do you see NRS waypoints as being the same or different as named waypoints?

3. How do you use NRS waypoints (Playbook routes, pilot-requested re-routes, ATC re-routes tactically to deviate around weather, to take advantage of winds/more direct routing, etc.)?
4. Are there facility or Agency guidelines regarding the use of NRS waypoints? If so, what are they and why? (Safety, reliability, workload management, etc.).

5. Do you find the current granularity/density of waypoints sufficient for your use?

6. Would you consider your use of NRS waypoints to be heavy, moderate, light?

7. What procedures are required to enter NRS waypoints into a flight's clearance?
    a. Are there any issues/problems with regard to this procedure? If so, what are they?

8. What issues or problems have turned up in Air Traffic Controller/Traffic Management Unit use of NRS waypoints?
    a. What do you believe is the most frequent type of ATC issue or problem associated with NRS waypoint usage?
    b. What type of problem related to ATC do you believe is the most consequential and why?

9. What issues or problems have you seen in flight crew use of NRS waypoints?
    a. What do you believe is the most frequent type of issue or problem related to pilots associated with NRS waypoint usage?
    b. What type of problem related to pilots do you believe is the most consequential and why?

10. Are there any issues with displaying NRS waypoints on your scopes/displays? If so,
    a. What are they?
    b. How do these issues affect you use of NRS waypoints, if at all?

11. How do you identify which aircraft are capable of using NRS waypoints?

12. What (other) issues have you identified regarding using NRS waypoints?
    a. Pilot familiarity?
    b. Spatial/geographic orientation?
    c. Keypunch/NRS waypoint name manual entry?
    d. Aircraft database limitations?
    e. Workload?
    f. Coordination:
        i. Between air traffic controllers?
        ii. Between you and the pilots/flights
    g. Transitions between one NAV system and another? NRS/Airway?
    h. Naming system – learning/orienting?
    i. Clearance readbacks/hearbacks?

13. What issues exist, if any, in managing mixed capable aircraft (some are NRS capable, some are not, some can accept a larger number of NRS waypoints than others, etc.)?

14. What advantages or disadvantages do you find from using NRS waypoints?