FLIGHT MANAGEMENT COMPUTER (FMC) NAVIGATION DATABASE CAPACITY

Albert A. Herndon
The MITRE Corporation's Center for Advanced Aviation System Development
McLean, Virginia 22102

Abstract

Navigation database (NDB) capacity (memory size) has always been an issue in aircraft Flight Management Computers (FMC). And, that issue is a concern for Performance-based Navigation (PBN) Implementation as so many new next generation (NextGen) procedures are being developed and many FMCs no longer have the capacity for additions to their NDBs. For the near-term, the problem will just keep getting worse for aircraft with FMCs limited by capacity due to the growth in the number of coded procedures and waypoints to store and limitations in the storage size. Anecdotal evidence finds navigation database suppliers estimating that worldwide procedure production will increase database size approximately 3% to 8% annually for the forseable future.[1] In many cases, the airlines must already strictly tailor the available sets of procedures in their databases according to geographic areas to meet current FMC memory capacity constraints. Fortunately, the trend for the mid-term and far-term is that the projected growth rate will not be such an issue given the actual and "potential" additional memory expansion of new FMCs.

However, a related concern is a means to move away from the binary packing of data into a general standard that works with all FMCs. Database development groups are proposing using a version of Extensible Markup Language (XML) which will take up significantly more storage. FMC vendors and airlines have expressed concern over this proposal because of memory storage requirements. This proposal is still in its infancy and has yet to be proposed as a formal standard.

This paper provides background on FMC database capacity and factors that influence memory requirements. It addresses airline's tailoring of navigation databases and the status of memory in current FMCs operating within the United States National Airspace System (NAS). It also introduces the methods the airlines use to reduce the size of their NDBs despite the tide of procedures being developed worldwide.

Introduction

All modern transport category aircraft have Flight Management Systems (FMS). The FMS consists of navigation radio receivers; inertial reference systems; air data systems; navigation, flight and instrument displays; flight control systems; engine and fuel system; and data link. These subsystems are managed and processed by the Flight Management Computer (FMC).

The FMC provides the primary navigation, flight planning, and optimized terminal routes and en route guidance for the aircraft and is typically comprised of interrelated functions such as navigation, flight planning, trajectory prediction, performance computations, and guidance.

The FMC and associated databases are an essential part of modern airline avionics. An FMC typically contains three databases in addition to the basic operational flight program (OFP). The first is a software options database which activates the optional functionality contained in the OFP that is desired by the operator. The second is the model and engine performance database and contains all the aircraft performance data which allows the FMC to compute fuel burn, optimum altitudes and airspeeds, etc. The third is the navigation database (NDB). The NDB contains all the information required for building a flight plan and processing that plan when airborne. All these databases are stored in the FMC on an electrically erasable programmable read-only memory (EEPROM) card. Each of these databases can be updated via a data loader.

[1] Jeppesen, Lido, EAG

The NDB contains terminal and en route fixes; waypoints and navigation reference system (NRS) grid points; intersections; airways including high altitude "jet" airways, low altitude "victor" airways, "T" routes, "Q" routes and oceanic routes; radio navigation aids such as distance measuring equipment (DME), very high frequency (VHF) omnidirectional range (VOR), and instrument landing systems (ILS). It also contains airports; runways; standard terminal arrival routes (STAR); standard instrument departures (SID); holding patterns; and instrument approaches such as VOR, non-directional beacon, area navigation (RNAV), required navigation performance (RNP), satellite based navigation system (SBAS), and ground based navigation system (GBAS). The data format specification for the NDB is defined in ARINC 424.[2]

Scope

This paper describes the navigation database capacity of FMCs, factors influencing NDB size and manufacturer and airline issues. The data depicted was obtained from airlines, and database suppliers and providers in 2011 and early 2012.

Background

Current high-quality data in the FMC are essential for optimum and safe navigation. Quality and integrity of the data in the United States is governed by Federal Aviation Administration (FAA) Advisory Circular (AC) 20-153A, *Acceptance of Aeronautical Data Processes and Associated Databases*[3]. Using the on-board FMC the pilot can assess flight-relevant information from the aeronautical data provided in the NDB which is updated every 28 days.

Figure 1 represents the layering structure of a typical FMC. Level 1 is company route data, Level 2 is the 28 day navigation database and Level 3 is "other" nonessential data. These levels comprise permanent, supplemental and temporary data. Each category has a finite capacity for data. An example of permanent data is a runway. Supplemental data can only be entered on the ground and then is stored indefinitely but may be deleted by the crew. Temporay data is automatically deleted after the flight is completed.

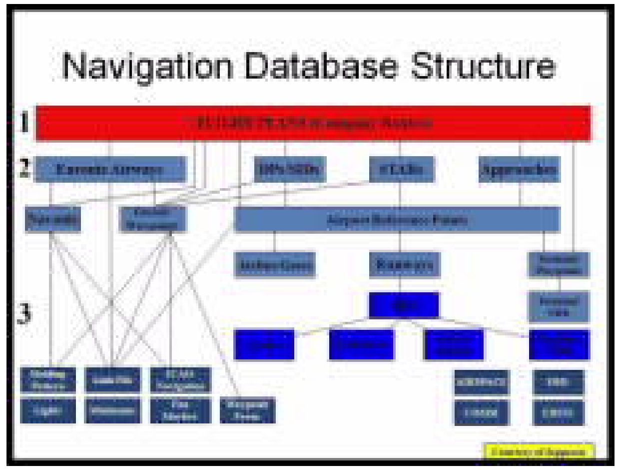

Figure 1: Typical Navigation Database Structure

There are three primary commercial providers of navigation data in the world. They are Jeppesen Sanderson based in Centennial, Colorado, owned by the Boeing Company; Lido/FMS in Zurich, Switzerland, owned by Lufthansa Systems; and the European Aeronautical Group (EAG) with the navigation data division located in Walton-on-Thames, Surrey, United Kingdom, owned by NavTech. Each of these companies compiles, maintains and updates a worldwide navigation database coded into ARINC 424[4] format. The data is obtained from the Aeronautical Information Publications (AIP) of all the International Civil Aviation Organization (ICAO) States.

The data is updated via the commercial 28 day single Aeronautical Information Regulation and Control (AIRAC) cycle detailed in ICAO *Annex 15, Aeronautical Information Services (AIS)*[5] document which defines a series of common dates and an associated standard aeronautical information publication procedure for States. A double cycle is 56 days and is used by some government entities such as the FAA. Cycles are designated by a four digit code "YYcc," where "YY" represents the calendar year, and "cc" indicates the sequential cycle number for the calendar year. Cycles may span from one calendar year to the next. An example is that the last cycle for 2011, numbered 1113, valid from December 15, 2011; rolled into 2012, valid until January 11, 2012. The first cycle for 2012 was 1201

[2] ARINC [1]
[3] AC 20-153 [2]

beginning January 12, 2012.

When the data is updated by the commercial providers the master ARINC 424 file is sold to the flight management computer manufacturers where the file is packed in a proprietary format to function in their specific FMCs. These FMC manufacturers include Honeywell, General Electric (GE), Thales, Universal Avionics, Rockwell Collins International, CMC Electronics, Garmin and Avidyne. As airlines may contract for NDBs from any one of the three data providers, the FMC manufacturers must build three sets of data for their FMCs. An example would be GE which has FMCs installed in all the Boeing 737-300/900 series aircraft. A U.S. B737 airline operator may contract with Jeppesen, while a South American airline may use Lido, and a European airline may use EAG. The evolution of the NDB from start to finish is shown in Figure 2.

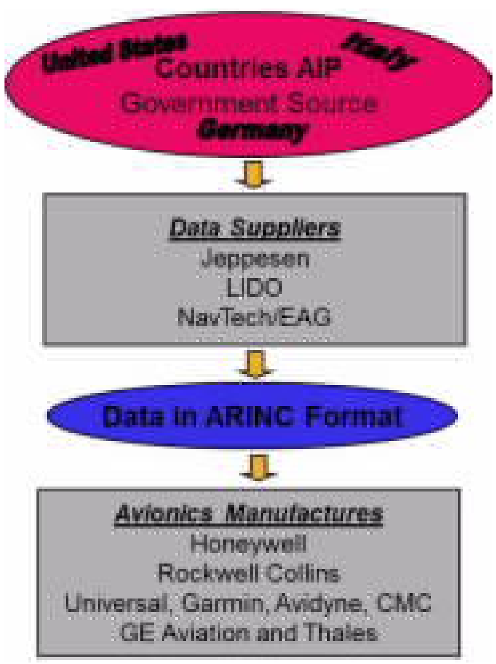

Figure 2: Evolution of the NDB

NAVIGATION DATABASE CAPACITY

A major issue for implementation of new procedures is the fact that the capacity of NDBs in many FMCs is limited. The issue is characterized in Figure 3.

The FAA *Instrument Flying Handbook*[6] explains that as the data in a worldwide database grows more detailed, the required data storage space increases.

Over the years that FMC's have developed, the size of the commercially available airborne navigation data has grown exponentially.

Later, this paper will illustrate that some manufacturer's systems have kept up with this growth and some have not. Many of the limitations of older systems are a direct result of limited data storage capacity. For this reason, avionics manufacturers and individual airlines must make decisions regarding which types of data records will be extracted from the master ARINC 424 database to be included with their system. For instance, an older FMC rarely includes all of the waypoints that are coded into master databases. Even some modern FMC's, which typically have much larger storage capacity, do not include all of the data that is available from the database providers. The manufacturers often choose not to include certain types of data that they think is of low importance to the usability of their FMC and airlines further reduce data that is not pertinent to their operation and route structure.

At the request of an airline a manufacturer may reduce the size of the data storage required in their avionics by limiting the geographic area the database covers. Like paper charts, the amount of data that needs to be carried with the aircraft is directly related to the size of the coverage area. Depending on the data storage that is available, this means that the larger the required coverage area, the less detailed the database may be. Size and capacity management of data will be discussed later.

[4] ARINC [1]
[5] Annex 15 [3]
[6] FAA IFH [4]

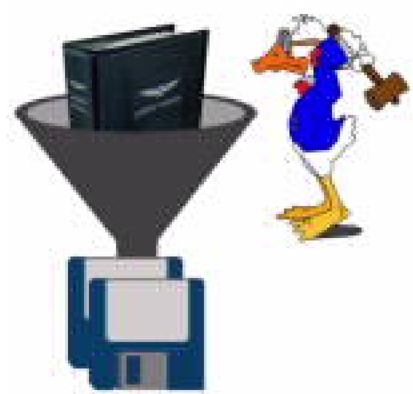

Figure 3: Characterization of NDB Capacity

Database Size

The Jeppesen GE worldwide NDB (this refers to the Jeppesen data that is used in the GE Aviation NDB for their FMCs) for runway ends over 5,000 feet with an instrument approach procedure (IAP) is currently (cycle 1203) 7,877 kilobytes (KB) or 7.8 megabytes (MB). A recent worldwide Lido GE 28 day NDB for runways over 5,000 ft was 6 MB. A recent Jeppesen Universal worldwide NDB for runways over 2,000 ft was 8.2 MB and the one for runways over 5,000 ft was 7 MB. Note that Jeppesen, Lido and EAG do not necessarily provide data for the same airports and runways.

GE has estimated their NDB will grow up to 3% per year through 2020 and Lido is predicting a 6% to 8% growth per year in their database. Referencing the Navigation Database Strcture in Figure 1, the NDB sizes mentioned above do not include company routes nor do they include data such as gates, floating waypoints, NRS grid points, "special" procedures and other tailored airline data.

Within the NAS, there are many FMCs that would not hold a worldwide NDB nor come close to holding a U.S. only NDB. FMC database capacity is reported in "words" and/or "bytes." A comparison of reported capacity values is not straightforward since manufacturers may use data compression techniques and different processor architectures (i.e. 16 bit, 32 bit, or 64 bit). A 16 bit processor represents 2 bytes. A byte is 8 bits and a binary bit is a one or zero. A word represents 16 bits or 2 bytes. In a 32 bit processor a Double Word (DWORD) is available and represents 32 bits or 4 bytes of data. In the newer 64 bit processors a Quadruple Word (QWORD) represents 64 bits or 8 bytes of data. In modern computers, a single character consumes 2 bytes of data in memory. So the word "fix" would consume 6 bytes.

NDB procedures are built using records made up of words.[7] Examples are in Table 1. Word counts are relevant when reviewing "Word" capacity in Tables 2 and 3.

Table 1: Words per data type

Courtesy of Honeywell	
DATA TYPE	**WORDS/ RECORD**
VORs	7
NDBs	6
Waypoints	5
Geo Coordinates	21
Airways	1
Holding Patterns	4
Airports	13
Runways	10
Procedure Name	5
Gates	5
Route Name	3

In Table 2 are examples of some current airline FMCs with limited NDB capacities which are operating in the NAS. The table is divided into three sections: Data from Aircraft Manufacturers, Data from Avionics Manufacturers and Data from Airlines. Table 3[8] represents the approximate amount of aircraft currently operating in the NAS with limited NDB capacity. When reviewing Table 2, refer to the Navigation Database Capacity, Database Size section above that describes a typical worldwide NDB's range from approximately 6 MB to 8.2 MB in

[7] ARINC 424 [1]
[8] MITRE U.S. Air Transport Fleet RNAV/RNP Capability Report dated February 2, 2012

size.

Table 2: FMC NDB Capacity from Aircraft Manufacturers, Avionics Manufacturers and Airlines. Highlighted in yellow are FMCs with the most limited NDB capacity.

AIRCRAFT	FMC TYPE/VERSION	CAPACITY "WORDS"	CAPACITY "BYTES"
	DATA FROM AIRCRAFT MANUFACTURERS		
B737-NG	GE U10.6, U10.7, U10.8	4 Mw	8 MB
B737-NG	GE U10.8 with new FMC hardware	8 Mw	16 MB
B747-400	Honeywell 747-4	1 Mw	2 MB
B747-8	Honeywell NextGen	50 Mw	100 MB
B757/767	Honeywell 200K FMC	200 Kw	400 KB
B757/767	Honeywell 700K FMC	700 Kw	1.4 MB
B757/767	Honeywell 1 Meg Non-PIP, PIP	1 Mw	2 MB
B757/767	Honeywell 2 Meg Non-PIP, PIP	2 Mw	4 MB
B757/767	Honeywell Pegasus Pre 2009	2 Mw	4 MB
B757/767	Honeywell Pegasus 2009	3.8 Mw	7.5 MB
B777	Honeywell AIMS 1	1 Mw*	2 MB*
B777	Honeywell AIMS 2	6 Mw	12 MB
B787	Honewyell	15 Mw	30 MB
A320	Honeywell Pegasus P1	2 Mw	4 MB
A320	Honeywell Pegasus P1-A	10 Mw	20 MB
A320	Thales FMS1	200 Kw	400 KB
A320	Thales FMS2 REV2+	2.5 Mw	5 MB
A320	Thales FMS2 R1-A	3.5 Mw	7 MB
A330	Thales FMS2 REV2+	2.5 Mw	5 MB
A330	Thales FMS2 R1-A	3.5 Mw	7 MB
A330	Honeywell Pegasus P3	2.7 Mw	5.5 MB
A340	Thales FMS2 REV2+	2.5 Mw	5 MB
A340	Thales FMS2 R1-A	3.5 Mw	7 MB
A340	Honeywell Pegasus P3	2.75 Mb	5.5 MB
A350	TBD	TBD	TBD
A380	Honeywell	10 Mw	20 Mb
E145	Honeywell NZ2000		8 Mb

E170	Honeywell Primus EPIC v17.X		8 MB
E170	Honeywell Primus EPIC v19.3 (16 Mb Capable)		8.57 MB
E190	Honeywell Primus EPIC v4.X		8 MB
E190	Honeywell Primus EPIC v19.3 (16 Mb Capable)		8.57 MB
	DATA FROM AVIONCIS MANUFACTURERS		
MD80/A300 ATR-42/72	HT9100	8 Mw	16 MB
Mooney M20J	Garmin GPS 155 - Americas-N (3 Mb Capable)		1.75 MB
Cirrus SR20	Garmin GNC 430/530 Legacy (8 Mb Capable)		7.53 MB
Ratheon King Air 200	Garmin GNC 430W/530W (16 Mb Capable)		12.12 MB
Embraer Phenom 100	Garmin G1000 (16 Mb Capable)		12.12 MB
CRJ-100/200	Rockwell Collins FMC4200	5 Mw	10 MB
CRJ-100/200	Rockwell Collins FMC4200 with LPV & RF Update	9.5 Mw	19 MB
CRJ-700/900	Rockwell Collins FMC4200	9.5 Mw	19 MB
B747-100	CMC CMA-900		8 MB
A300-600	CMC CMA-9000		17 MB
E145	Universal UNS-1C/D/K		8 MB
Q400	Universal UNS-1E/F/L		32 MB
Ratheon King Air 350	Universal UNS-1Ew/1Fw/1Lw	32 Mw	64 MB
	DATA FROM AIRLINES		
B757	Honeywell Pegasus 2001	2.3 Mw	
B757/767	Honeywell Pegasus 2005	2.3 Mw	
B757	Honeywell PIP 1M	1 Mw	
B757	Honewyell Plug and Play	2.3 Mw	
B757/767	Honeywell Legacy	1 Mw	
B737-300	GE U5.0	288 Kw	
B737-400	GE U10.5	3.5 Mw	
MD80	Honeywell HT9100		2 MB

MD88	Honeywell 926	650 Kw	
MD90	Honeywell 926	200 Kw	
A319/320	Honeywell 964	400 Kw	
A330	Honeywell PIP Load 16	1 Mw	

Table 3; Approximate number of NDB limited aircraft currently operating in the NAS. Data is current as of February 2, 2012

AIRCRAFT	NUMBER OF AIRCRAFT	FMC TYPE	CAPACITY "WORDS"	CAPACITY "BYTES"
737-300	9	GE U10.5	3.5 Mw	
737-400	1	GE U5.0	288 Kw	
747-400	97	Honeywell 747-4	1 Mw	2 MB
757-200	3	Honeywell Legacy	200 Kw	
757-200	145	Honeywell Legacy	700 Kw	
767-200	36	Honeywell Legacy	200 Kw	
767-200	15	Honeywell Legacy	700 Kw	
767-300	6	Honeywell Legacy	200 Kw	
767-300	20	Honeywell Legacy	700 Kw	
767-300	24	Honeywell Legacy		1 MB
777-200	123	Honeywell AIMS1	1 Mw	2MB
MD80	290	Honeywell HT9100	1 Mw	2MB
MD88	117	Honeywell 926	650 Kw	
MD90	28	Honeywell 926	200 Kw	

In the case of Table 3, for perspective, on February 2, 2012, there were 6,918 U.S. Code of Federal Regulations (CFR) Part 121 air carrier aircraft operating in the NAS[9] and 6,544 or 95% were equipped with FMCs.

Additional Capacity Issues

Some FMC's also have "procedure" capacity issues. Although one widely used FMC model has an 8 MB+ NDB capacity that may be expanded to 16 MB, it has issues at airports with over 100 arrival and departure procedures. Some airport examples where 100 arrival and departure procedures are exceeded include Cairo, Amsterdam, Madrid, Paris (Le Bourget, Orly and Charles de Gaulle), Mumbai, New Delhi and Beijing. A FMC service bulletin issued states that the aircraft may lose FMC applications in flight with over 100 procedures and flight plan up-linking.[10] Further, another manufacturer has a FMC model with a limit of 99 total procedures and a limit of 8 waypoints per procedure. A third FMC manufacturer has a model with a limit on the amount of arrivals, departure and approaches as shown below:

- Early models – limit of 70 departures, 70 arrivals, and 29 approaches at an airport.
- Later models – limit of 130 departures, 130 arrivals, and 39 approaches at an airport.

There is no additional proprietary information on the observations above, but they represent limitations unrelated to the total physical memory capacity that could require tailoring of a database. With every runway end at many large airports having an ILS, VOR, RNAV, RNP, and possibly a VOR and non-directional beacon approach with various SBAS and GBAS approaches being introduced, the 29 and 39 approaches may soon be exceeded.

Another FMC capacity issue is the number of waypoints available for processing. One widely used FMC with ample NDB capacity may store a maximum of 255 terminal waypoints for an individual airport. Some airports now exceed 300 waypoints.

A related concern is a means to move away from the binary packing of data into a general standard that works with all FMCs. Database development groups are proposing using a version of Extensible Markup Language (XML) which will take up significantly more storage. FMC vendors and airlines have expressed concern over this proposal because of memory storage requirements. This proposal is still in its infancy and has yet to be proposed as a formal standard.

Size or Capacity Management

With the advent of PBN procedures, the demand for increased NDB memory capacity will continue. Today, memory limitations require that some operators carefully customize their databases based on the individual needs of their operation. Airlines work around the capacity issues using size or capacity management techniques loading only the data that is needed in a particluar aircraft used on that aircraft's route structure either by sectors or geographic squares and rectangles. By restricting the loaded data in this manner, the capacity problem is solved and it is more economical for the airline as airlines pay for their database by "bit" (8 bits in a byte). However, it restricts the schedule flexibility of the airline since some of their aircraft are restricted to regions. Some examples: Virgin America has no need for southeast or southwest region procedures; Hawiian Airlines has no need for Alaska procedures (or mid west or east coast); Southwest Airlines has no need for Hawaii procedures; and Colgan Airlines only requires east coast procedures. In addition the large airlines with expansive route structures restrict certain aircraft types to geographic regions resulting in the decrease in scheduling flexibility mentioned above.

Airlines also continue to work with their data suppliers to customize the individual NDBs for their fleets based on particularized airframe, route or operational requirements. Examples of NDB size management are:

- Remove airports with procedures that are no longer needed for line operations.
- Remove some unneeded procedures from airport records such as conventional SIDs, STARs, and approaches (non-directional beacon, VOR, localizer, etc.).

[9] http://av-info.faa.gov/OpCert.asp
[10] Falcon Service News Flash [5]

- Remove all procedures from some airports but retain the airport. This will give the crew a visual location of the airport on the FMC Navigation (map) Display (ND) which allows the crew to extend the runway centerline for situational awareness in case of an emergency.
- Waypoint optimization such as removing NRS grid points or electing not to install NRS grid points in the NDB.
- Remove all holding patterns except those on missed approaches.

Conclusions

The Flight Management Computer (FMC) and associated databases are an essential part of modern airline avionics. Commercial air carrier and corporate flight department decisions concerning the initial purchase or retrofit of FMC hardware, make any issue of NDB capacity extremely important. Airlines are closely balancing expected operational benefit and subsequent NDB capacity issues with purchase requirements for new aircraft against the total capital investment required to maintain or upgrade current airframes. Until the cost and inconvenience of the capacity management process and associated issues exceeds the cost to purchase new aircraft or upgrade avionics, many airlines are either unwilling, or unable to incur additional costs based on memory capacity alone. Upgrading may make sense when additional memory capacity is coupled with improved performance and PBN capability, such as the ability to process radius-to-fix leg types and RNP alerting and monitoring. Many FMCs cannot be updated due to parts obsolescence.[11]

Navigational data volume grows on an annual basis because of new procedure development and the short term need to carry along legacy procedure types. Approaches are a significant part of the growth. The advent of X, Y and Z approaches; RNP Authorization Required (AR) approaches; SBAS and GBAS approaches; etc. has caused growth. These new approaches are in addition to established approaches. New RNAV SIDS and STARS in addition to conventional SIDs and STARs add growth. Everytime a waypoint or a NRS grid point is added to the NAS, it takes up to 5 “words” in the database. Below are examples of procdedure size estimates from one airline.

- The KPHX RNAV (RNP) Z RWY 26 uses as many as 500 “words” in the database or 1,000 “bytes” in a 32 bit system. The airline states that the “average” approach in their navigation database uses 100 FMC “words.”
- The KPHX BARGN ONE RNAV DEPARTURE uses as many as 1,500 “words” in the database or 3,000 “bytes” in a 32 bit system. The airline states that the “average” SID in their navigation database uses 500 FMC “words.”
- The KPHX GEELA TWO RNAV ARRIVAL uses as many as 1,000 “words” in the database or 2,000 “bytes” in a 32 bit system. The airline states that the “average” STAR in their navigation database uses 500 FMC “words.”

The examples cited above do not take into consideration database compression used by the various FMC manufacturers. For perspective, there were 11,624 RNAV and RNP AR approaches in the NAS as of March 6, 2012. In addition, there were 18,290 other instrument procedures, and 2,754 SIDs and STARs.

Database capacity is increasing in newer FMCs and/or hardware updates. At GE, the capacity of the FMC version U10.5 is 3.5 Mw while the U10.6 , U10.7 and U10.8a are 8 MB, and the U10.8a with a FMC hardware change is 16 MB. The new U11.0 coming in the Fall of 2012 will have larger memory. Thales FMS2 in the Airbus fleet has increased from 5 MB to 7 MB capacity. Honeywell has increased the B777 capacity from the AIMS1 BP2001 of 2 MB to the current AIMS2 BPv14 FMC with 12 MB. The B787 has 20 MB and the A380 has 30 MB. The Honeywell NextGen 100 MB FMC onboard the B747-8 and Gulfstream 650 is the future of FMC capabilities.

Navigation database capacity will continue to be an issue for NextGen through the near-term. The solution is that the airlines are slowly upgrading FMCs in their fleets. Through continued airline industry consolidation and new fleet purchases over the next decade, one can expect to see an increase in

[11] Wallace et al. [6]

navigational database capacity for the mid-term. Based solely upon data suppliers' projected annual increase of procedures produced, airlines will be required to increase FMC capacities to maintain a degree of competitive advantage and take advantage of PBN Implementation.

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Biography

Albert A. Herndon is a Principal Multi-Discipline Engineer at The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) on the PBN Operations Team. He has worked on PBN implementation, aircraft avionics capability and flight management systems differences both domestically and internationally for over 10 years and is a retired Naval Aviator and a retired Trans World Airlines Captain.

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Email Address

Albert A. Herndon aherndon@mitre.org

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