Appendix B

Reference Systems

B.1 Chart Reference Systems

Geodetic datums are reference coordinate systems used to establish the precise geographic position and elevation of features on the surface of the Earth. They are established at all levels of government (international, national, and local) and form the legal basis for all positioning and navigation. Within the last 2 to 3 decades, there have been great advances in our knowledge of the shape and size of the Earth (i.e., geodetic knowledge). Geodesy and navigation are to a large extent based on Earth Centered Body Fixed (ECBF) coordinate systems. These are Cartesian coordinate systems with origins at the center of mass of the Earth. The old datums have generally been based on localized surface monuments (and associated agreements) and were defined by a reference ellipsoid that was not Earth centered.

The Department of Defense (DOD) Global Positioning System (GPS) uses the World Geodetic System of 1984 (WGS 84) as its coordinate frame. WGS 84 is an ECBF coordinate system upon which all U.S. military and much civilian navigation will be based. Within the U.S., the National Geodetic Survey (NGS) is the primary civilian legal authority for the establishment of U.S. datums. Until recently, the horizontal datum used throughout most of the U.S. and Canada was the North American Datum of 1927. NAD 27 was not Earth centered. Until recently, nearly all nautical charts, aeronautical charts, Federal surveys, and associated data provided by the National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) were legally established with respect to NAD 27. In 1986, NGS completed a new horizontal datum known as the North American Datum of 1983 (NAD 83). NAD 83 is now the legal datum for surveying, mapping, and charting in the U.S. For purposes of navigation, mapping and charting, NAD 83 and WGS 84 are effectively equivalent (i.e., they differ by no more than a few meters from one another).

There is also a vertical (height) datum. Until recently, the legal vertical datum in the U.S. has been the National Geodetic Vertical Datum of 1929 (NGVD 29). In 1991, the NGS completed the North American Vertical Datum of 1988 (NAVD 88). NAVD 88 is now the legal vertical datum in the U.S. Vertical datum products and activities are being converted from NGVD 29 to NAVD 88. The conversion between GPS determined heights (ellipsoidal heights) and vertical datum (orthometric) heights is made by using a geoid model associated with the respective vertical datum. NGS has developed a geoid model, GEOID 93, to support such conversions.

B.2 Nautical Charts

Most nautical charts are based on regional horizontal datums which have been defined over the years independent of each other.

These include charts published by the Defense Mapping Agency (DMA) and NOS. In addition, in many parts of the world, the positional accuracy of chart features (such as hazards to navigation) sometimes varies from chart to chart and, in some cases, within a chart. Certain charts for waters in the southern hemisphere, for example, do not show islands in their correct geodetic positions, absolute or relative. Therefore, datums and limited chart accuracy must be considered when a navigational fix is plotted by a navigator on a nautical chart. Modern navigational positioning is based on satellite systems which are geocentric by definition, and these satellite coordinate systems differ significantly in many cases with the local or regional datums currently used for nautical charts. In addition to this difference, the plotted detail, such as soundings and navigational aids, contain a minimal plottable error that ranges between 0.5 mm and 1.0 mm on paper.

Virtually all radionavigation equipment incorporating coordinate converters (automatic computation of geodetic latitude and longitude from data received from a radionavigation system) were, until recently, programmed with the World Geodetic System of 1972 (WGS 72). Today, new radionavigation equipment coordinates, especially from differential GPS systems, are computed based on WGS 84, or, equivalently, in the U.S., NAD 83.

The large majority of the nautical charts published by NOS have been compiled based on a regional datum: NAD 27. The remaining NOS nautical charts were published on eight other local or regional datums. As stated, NOS has now adopted a geocentric datum: NAD 83. NOS has begun the conversion of most of its nautical charts to NAD 83. The charts of the Pacific islands, published by NOS, will be compiled based on WGS 84. As stated before, for charting purposes, NAD 83 is equivalent to WGS 84. As charts are converted to NAD 83, datum transformation notes will be added which report the amount of shifts from NAD 27 coordinates for each chart. These shifts can be in excess of 100 m and care must be taken not to mix NAD 83 and NAD 27 values while navigating.

Improvements in worldwide navigation accuracy, which are occurring with the implementation of GPS, will be significant. However, the ability to navigate safely along the coastlines of the world and on the high seas will remain limited where accurate, up-to-date hydrography and associated topographic features are not all positioned on the same satellite-based reference system.

B.3 Aeronautical Charts

The ultimate responsibility for the accuracy of air cartographic positional data rests with NOS. Section 307(b)(3) of the Federal Aviation Act authorizes the FAA, subject to available appropriations, to arrange for the publication of aeronautical maps and charts necessary for the safe and efficient movement of aircraft in air navigation utilizing the facilities and assistance of other Federal agencies. NOS, in turn, provides many of these services. Within the National Airspace System (NAS), the NGS establishes the basic U.S. datum that legally controls all positioning within the U.S. The Nautical Charting Division (NCD) of NOS conducts the Airport Obstruction Clearance Surveys (OC Surveys) which establish the positioning of 750 U.S. major civil airports and all navigation aids to existing U.S. datums. The NGS has completed the Airport Datum Monument Program (ADAM) which establishes datum monuments on 1400 non-OC surveyed airports. The ADAM data, which include end-of-runway coordinates, were determined using GPS and are available in NAD 27 and NAD 83 datums. The FAA has converted aeronautical charts to NAD 83. NOS is currently undertaking a large re-observation program to obtain high-accuracy NAD 83 positions at U.S. airports.

The FAA conversion from NAD 27 to NAD 83 has a major impact on the FAA. All positional data currently used within the NAS requires conversion. The NGS has determined that the horizontal differences between NAD 27 and NAD 83 are as large as 450 m in Hawaii, 160 m in Alaska, and 100 m in the central U.S. The horizontal differences are not uniformly distributed. Vertical datum differences are relatively minor and the transformation will be performed after the horizontal datum conversion. GPS equipment derives position information referenced to WGS 84. Databases produced for use in the contiguous U.S., Alaska, and Hawaii contain coordinates referenced to NAD 83 and NAVD 88. For the purposes of aircraft navigation, coordinates referenced to NAD 83 and NAVD 88 correspond to the coordinates for the same locations referenced to WGS 84.

B.4 GPS and the Evolution of Charts and Datums

Historically, there has been a horizontal datum (e.g., NAD 27 and the original NAD 83) and a vertical (orthometric) datum (e.g., NGVD 29 and NAVD 88). GPS has provided the means to develop a three-dimensional datum. Once the NGS revisited NAD 83 monuments and made extensive high-accuracy measurements, NAD 83

became three dimensional. The three dimensions are geodetic latitude, longitude, and ellipsoid height. Ellipsoid height is the height above a specified Earth-centered ellipsoid. Orthometric height remains referenced to NAVD 88 and is based on spirit leveling and is traditionally thought of as the height above mean sea level. Orthometric height and ellipsoid height can differ by about 100 m, and thus there can be no room for confusion when landing an airplane!

By interagency agreements between NOAA and the USCG and the FAA, NGS will precisely measure the location of USCG Beacon sites and FAA Wide Area Augmentation System sites. These will be continuously operated reference sites (CORS). Besides the USCG and FAA sites there are others such as those operated by the U.S. Army Corps of Engineers (COE), NOAA, and other organizations. NGS will determine and monitor the geodetic positions of these CORS at the decimeter (or better) level.

Thus, for the first time, all radionavigation users will have the opportunity to reckon position precisely and based on the same geodetic datum. Whereas, up to the present time, nautical and aeronautical "paper" charts have provided no better than few meter resolution, the advances described above permit "paperless" or digital charts to have greater resolution and accuracy. For the first time, the systems upon which the chart is made and used will be the same.

B.5 Electronic Chart Display Information System (ECDIS)

The Electronic Chart Display Information System (ECDIS) has emerged as a promising navigation aid that will result in significant improvements to maritime safety and commerce. More than simply a graphics display, ECDIS is a real-time geographic information system (GIS) that combines both spatial and textual data into a readily useful operational tool. As an automated decision aid that is capable of continuously determining a vessel's position in relation to land, charted objects, aids to navigation, and unseen hazards, ECDIS represents an entirely new approach to maritime navigation and piloting. It is expected that ECDIS will eventually replace the need to carry paper charts.

The development of an international performance standard for ECDIS was finalized by the International Maritime Organization (IMO) in May 1994. The IMO Performance Standards for ECDIS is slated for formal adoption by the Nineteenth Assembly of IMO in September 1995. To ensure early dissemination, IMO issued ECDIS Performance Standards as MCS/Circ. 637 on May 27, 1994.

As specified in the IMO Performance Standards, the primary function of ECDIS is to contribute to safe navigation. ECDIS must be capable of displaying all chart information necessary for safe and efficient navigation organized by, and distributed on the authority of, government-authorized hydrographic offices. With adequate backup arrangements, ECDIS may be accepted as complying with the up-to-date

charts required by regulation V/20 of the Safety-of-Life-at-Sea (SOLAS) Convention of 1974. In operation, ECDIS should reduce the navigational workload compared to using the paper chart. It should enable the mariner to execute in a convenient and timely manner all route planning, route monitoring, and positioning currently performed on paper charts. ECDIS should also facilitate simple and reliable updating of the electronic navigational chart. Similar to the requirements for shipborne radio equipment forming a part of the global maritime distress and safety system (GMDSS), and for electronic navigational aids, ECDIS onboard a SOLAS vessel should be in compliance with the IMO Performance Standard.

For the electronic navigational positioning system to be used with an IMO-compliant ECDIS, it is specified that:

- The vessel's position be derived from a continuous positioning system of an accuracy consistent with the requirements of safe navigation.
- A second independent positioning method of a different type should be provided; and, ECDIS should be capable of detecting discrepancies between the primary and secondary positioning systems.
- ECDIS provide an indication when the input from a positioning system is lost or malfunctioning.

When ECDIS and radar/Automatic Radar Plotting Aid (ARPA) are superimposed on a single display, they provide a system that can be used both for navigation and collision avoidance. As specified in the IMO Performance Standards, radar information may be added to the ECDIS display, as long as it does not degrade the display and is clearly distinguishable from the electronic navigational chart. The IMO Performance Standard further stipulates that both the ECDIS and radar use a common reference system (e.g., GPS/DGPS), and that the chart and radar image match in scale and orientation.