Geodesy in Aviation, Implementation of the WGS 84 Datum for the Global Navigation Satellite System.

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Abstract: The importance of the geodetic airfield survey is addressed in this paper. The author discusses the importance of the Global Navigation Satellite System (GNSS) in aircraft approach and departure procedures and the critical aspect of the airfield survey and the effect various datums will have on the implementation of the system. Further discussion is given to the purpose and procedures required to conduct the airfield survey including setting of the PACS and SACS, location of runway features determining the runway profile, and the positioning of NAVAIDS and vertical obstructions. The author also addresses the issue of quality assurance of the field survey work required for the airfield survey.

1. Why Geodetic Airport Surveys?

While the ground-based navigation system guides an aircraft from one navigation station to another, the satellite-based navigation system guides an aircraft from one set of coordinates (latitude, longitude) to another. An earth reference system, or datum, is used to produce latitude and longitude values for a point in space such as a runway threshold, an obstacle or an aircraft in flight. ***Over 260 datums are in use in the world at present***. Each of these datums will produce different latitude and longitude values for a given point in space. The differences vary from several meters to several hundred meters.

The GPS system is based on the World Geodetic System - 1984 datum, the datum adopted by ICAO. When GPS avionics is used for approach navigation it is vital that the coordinates for the destination airport also be referenced to WGS-84 otherwise the aircraft's ground track will be different than what should be and obstacle clearance will not be assured. In Chile, for example, if GPS avionics is used to fly to a north/south runway using runway coordinates expressed in the local datum (Provisional SA 1956) then the aircraft's final course will be 245 meters east of the centerline. In addition, the pilot will begin his/her descent from the final approach fix (FAF), will call the missed approach point (MAP), 462 meters prior to the intended FAF/MAP.

Neither the FAA nor ICAO approves the use of coordinate transformation software programs when developing approach and departure procedures because the transformation accuracy is

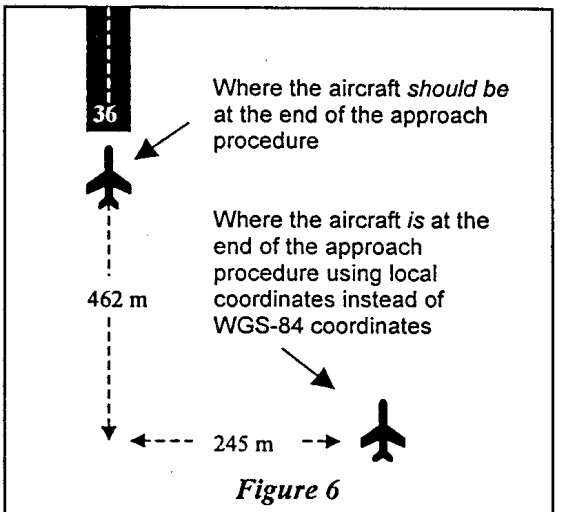

Figure 6

insufficient. During the en route phase a navigation error of several hundred meters is generally not significant because en route airways incorporate a generous lateral and vertical obstruction buffer. That is why GPS en route navigation has been implemented in several States that have not yet completed airport surveys referenced to the WGS-84 datum.

2. The Airport Survey

Geodesy, surveying, photogrammetry, and mapping are at the heart of implementing the GNSS. The Council of the International Civil Aviation Organization (ICAO), at the thirteenth meeting of its 126th Session on 3 March 1989, approved Recommendation 3.2/1 of the fourth meeting of the Special Committee on Future Air Navigation Systems (FANS/4) concerning the adoption of the World Geodetic System - 1984 (WGS-84) as the standard geodetic reference system for future navigation with respect to international civil aviation and for all

GPS based navigation systems. As the aircraft will have the primary role in navigation, based on its position as determined by GPS, the runway will become a passive element. If the aircraft and the runway are not on the same datum, we will have problems.

The Surveyor/Geodesist has a very important role in the development of the GNSS. His role, as always, is to make sure the airport is where it is supposed to be relative to all of the other airports in the world. Today's surveyor does this with GPS and WGS 84. The five basic steps to performing an airport survey critical to the design of a GPS approach are: (1) Positioning the PACS; (2) Positioning the SACS; (3) Locating the runways; (4) Locating the navigational aids; (5) Locating all vertical obstructions

3. PACS

The Primary Airport Control Station (PACS) is the heart of the airport survey. This monument will provide the basis for all future surveys of the airport so it must be precisely positioned, permanent in character and set in a secure location. Generally the PACS is set on the roof of the terminal or control tower. This is a secure location that is not generally accessible to unauthorized people. In many cases the actual monument consists of a 50 cm diameter brass or aluminum cap set in the top of a bearing wall of one of these structures. If there is not a good location on a building roof, then a secure site should be found and a brass cap set in the top of steel rod, driven to refusal may be used. The stamping on the cap should follow the recommendations set forth by IACO in their WGS 84 Survey Manual.

The position is determined by GPS and it must be accurate to within 0.6 meters relative to the global WGS 84 datum.[1] It cannot be positioned relative to any local mapping datum it must be positioned relative to the WGS 84 global reference datum. This is why autonomous or absolute point positioning techniques are strongly recommended unless the airport is located in a region where a WGS 84 (or ITRF 96) based high accuracy reference network (HARN) has been developed and documented. It is mandatory that dual frequency, geodetic level GPS receivers and fixed height tripods be used for all of the GPS work. You can use single frequency receivers for the relative GPS positioning work involved in setting the SACS or locating the runways, but you must use a dual frequency receiver to position the PACS.

The most practical method for positioning the PACS is to use absolute GPS positioning with at least 3 consecutive, non-contiguous twenty-hours GPS data collecting sessions. Each session should be independent of one another yet consecutive in nature. This will allow for several passes of the full GPS constellation to be used in resolving the final point position. Post processing should be carried out in the field using the broadcast ephemeris for preliminary point positioning and quality assurance of the data sets collected. To determine the final position, you must use the precise GPS ephemeris for those observation sessions. This may be downloaded from several sources including the GPS equipment manufacturer's Web site. Another, far easier method, is to contact the United States National Imaging and Mapping Agency (NIMA) and arrange for them to reprocess your data using their proprietary GYPSI-OASIS or NIMA GASP software. The data can be uploaded to their FTP from anywhere in the World. The processing turnaround time runs about three days. This is a very good check on the quality of your data and the resolution of the final position of the all-important PACS.

4. SACS

The next step is to position three to four Secondary Airport Control Stations (SACS) relative to the PACS. The SACS should be permanent monuments that should be set in secure locations, yet will be accessible to other surveyors in the future. The most common monument is a steel rod driven to refusal. These are the control stations that will form the basis for all future airfield expansion or construction They should be established at points that are visible with at least one other station so local surveys may be able to use conventional survey techniques for future surveys. The SACS are usually positioned using standard relative

[1] ICAO specification, NIMA requires 0.42 meters.

GPS methods and they should have a positional accuracy of 0.05 meters relative to the PACS.[2] This can take place while the PACS is being positioned and a "Dummy" value assigned to the PACS until the final position is resolved. This method will allow you to maintain your productivity and check quality as you are going.

The observation time needed to position each SACS will depend upon the receivers used (single or dual frequency), GDOP, PDOP, and VDOP of the GPS constellation and the procedures used. Under normal circumstances, using modern dual frequency receivers it should take two one-hour data sessions to position each SACS. Keep in mind that I am recommending two sessions here for increased accuracy and quality. Redundancy of measurements is critical in aviation geodesy. You should be able to complete all of the data collecting for the SACS within two days, simultaneous to the data collecting for the PACS.

5. Locating the Runways

The third step is the survey of the runways. This includes locating the runway ends, thresholds, length, width and profiling the runway. Runway data shall be provided for all runways existing at the time of the field survey. Unless otherwise stated, all runway points shall be on the runway centerline. The number painted on the runway at the time of the field survey shall identify runways. If a number is not painted on the runway, the runway number published in the "Terminal Procedures" current at the time of the field survey shall be used. This is normally accomplished with relative GPS measurements using either the PACS or SACS as the controlling monuments. Standards and specifications for this step are available from ICAO, NIMA, or the United States National Geodetic Survey (NGS). Below is a listing of normal runway features that must be identified and positioned.

- Airport Elevation Point
- Runway Ends (H&V)
- Displaced Thresholds (H&V)
- Runway Profile–normally at 25-meter intervals also locating the centerline (H&V)
- Runway and shoulder widths (H)
- Touchdown Zone (H)

6. Locating the NAVAIDS

Locating the navigational aids (NAVAIDS) is quite a tricky proposition. If you are not a pilot or very familiar with visual or radio navigation you will need assistance from the airport engineer in identifying the many possible NAVAIDS at an airport. They can range form visual aids such as a Visual Approach Slope Indicator (VASI) to radio based equipment such as radar towers, non-directional beacons VORS and glide slope indicators. There are published standards and specifications for locating each NAVAID that can be obtained from the sources stated above. The key to locating the NAVAIDS is redundancy of measurements. Whether using GPS, total stations or intersection angles, you should obtain sufficient measurements to produce a closed traverse. This is the only way to insure the quality of the work. Some NAVAIDS, such as ILS Localizers and VASIs will allow for direct GPS measurement. If this is the case you must take enough GPS data points to be able to construct the shape of the object. Taking direct measurements of the NAVAID with a surveyor's tape will allow you to check the results of the GPS points. Again, this is a confidence raising measure.

When locating other NAVAIDS such as VORS or NDB towers you will need to establish several GPS survey points around the object. Then occupying each GPS survey point, with a surveyor's theodolite or Total Station, and sighting another GPS survey point you will be able to measure the horizontal and vertical angle to the inaccessible point on the NAVAID. By a process of intersections and triangulation the surveyor will be able to calculate the position of the object with enough redundancy so as to have a 100% level of confidence in the position. For additional information NIMA publishes a document showing photographs of the most common NAVAIDS and indicating thereon the required point for the surveyor to locate.

[2] ICAO Standard, NIMA requires 0.03 meters.

7. Vertical Obstructions

The last and toughest part of the survey is locating the vertical obstructions. Vertical obstructions are considered as any structure or topographic feature penetrating something called the Obstruction Identification Surface (OIS). There are 3-D models defining the OIS and they are based on landing patterns of the aircraft. The surveyor will need to check with the governing agency requesting the survey to determine the OIS to be used. A few examples of vertical obstructions are; control towers, radio towers, light standards, buildings, radar towers, topographic features such as hills and trees. In general, the OIS is a model of the approach glide path extending out seven nautical miles from the ends of the runway. ***(See Figures 1-4 in Appendix A)*** The method for locating obstructions is the same as described above for NAVAIDS.

Vertical obstructions may also be located using photogrammetric methods. Photogrammetry can be a very cost effective means of locating obstructions, but caution should be taken here. Many obstructions are tall, skinny structures such as radio towers that can be missed when using photogrammetric means.

Airports are considered as secure areas for many reasons. The governing agencies such as the FAA require strict adherence to ingress and egress security. Airport managers are concerned about debris on the runway and interference with ground traffic and aircraft. Airlines and controllers do not want unauthorized persons roaming active runways or using radios. In some cases, the surveyor will need to work off hours to complete the survey work. In these cases, however, the surveyor must coordinate his or her work with the appropriate airport management on a daily basis and concede to their wishes.

8. Remote Sensing for Obstructions

There are studies underway by various agencies and private industry to determine the value of airborne and spaced-based remote sensing for the locations of vertical obstructions. Airborne photogrammetric mapping is a proven method of locating obstructions. The two major problems with this method are (1) the cost for the photogrammetric mapping and (2) the ability to obtain the aerial photography. The costs for the mapping may exceed the total cost of the ground survey, but the resultant digital mapping is invaluable. The issue of obtaining the aerial photography may be present the larger impediment as many nations have very severe restrictions to aerial photography over their territory, especially airfields.

9. Reports

The final task in any airport survey is the preparation of the Final Reports. These reports should be detailed and at minimum contain the following information.

- A description and map of the airports general geographic location
- A complete narrative of the work done, who performed the survey, dates, what was done, and any problems or issue encountered
- Tables listing all of the measured and computed positions in latitude, longitude, ellipsoidal height, UTM grid coordinates and mean sea level related (Geodial) heights.
- CAD developed drawings of all monuments positions and reference locations, GPS observation schemes, runway planimetrics and profile, NAVAID locations and a general airport plan.
- Copies of sketches or drawings indicating the position and character of the PACS and SACS showing ties to nearby features so that these control points may be quickly recovered.
- Digital photos of all PACS, SACS, runway features, NAVAIDS, vertical obstructions, and other general airfield features.
- Copies of any ancillary materials acquired for the survey, such as survey records and topographic maps.