GEODESY IN AVIATION,
Implementation of the WGS 84 Datum for the Global Navigation Satellite System

2001 International Symposium on GPS/GNSS

Fred Henstridge
November 8, 2001
Jeju Island, Korea
PRESENTATION AGENDA

- What is CFIT
- The Importance of GNSS
- Datums
- Purpose of WGS 84 Surveys
- Typical Airfield Survey
- Quality Assurance
- GIS for Airports
- Discussions
CFIT- It Does Not Have to Be

- Controlled Flight Into Terrain (CFIT)?
- 33% of all Fatalities since 1985
  - Guam, Aug. 6, 1997  228 Fatalities
  - Van, Turkey, December 29, 1994  54 Fatalities
  - Philippines, Feb. 2, 1998  104 Fatalities
  - El Salvador, Aug. 8, 1995  65 Fatalities
  - Buga, Colombia, Dec. 20, 1995  160 Fatalities
  - Arequipa, Peru, Feb. 29, 1996  123 Fatalities
  - Indonesia, Dec 19, 1997  97 Fatalities

- The List Goes On ..........................
Satellite-based Navigation Offers Substantial Safety and Operating Benefits Vs. The Existing Ground-based Navigation System

A Boeing Study Covering 1986 to 1996 Determined That Large Commercial Jets Have Crashed in Latin America at a Rate of 4.5 Per Million Flights, Three Times the World Average and Nine Times the U.S. Average

The Majority of CFIT Accidents Occur During the Final Descent, on Course but Short of the Runway
Advantages to GNSS

- Safer
  - All Weather Functional
    - Can Land Aircraft in All Weather
  - Human Element Minimized
  - Collision And Flight Into Terrain Avoidance
  - More Accurate Instrument Approach Procedures

- More Efficient Air Traffic Management
  - Saves Time
    - Increased Airport Acceptance Rates
  - Saves Fuel
    - Increases Pay Loads
    - Less Costly
  - Increased Use of Airspace

Saves Lives
GPS Navigation

Global Navigation Satellite System (GNSS)

Ground Controlled Route

GNSS Route
Geodesy

- Describing the Earth
  - Shape of Earth (Big Potato)

- Definitions
  - Spheroid or Ellipsoid
  - Datum
  - Geoid
    - Gravity Field
    - Mean Sea Level (MSL)
  - Visual Presentation (Maps and Charts)
    - Coordinates
    - Projections
Geodetic Datums

- Numerous World-Wide Datums
  - 280+
- 100 Years Old
- Best Fit for a Local Area (Country)
- Used Mainly for Mapping
- Not Suited for Global Data Interchange
Local Geodetic Datums

- >200 Datums in the World In Use Today
  - Scientific and Political Reasons

- Much Disagreement
  - Scientific and Political Reasons

- GPS Navigation Requires Agreement
  - Common Ellipsoid and Height Reference (Horizontal and Vertical Datum)
  - An Aircraft Leaving Point “A” and Flying to Point “B”, With the Assistance of GNSS, Needs to Have Both Points “A” and “B” Related to the Same Datum If a Safe Arrival Is Expected.
    - WGS-84 Is The Specified Datum by ICAO, The United States FAA and the DoD.
Ellipsoid

- Mathematical Model of the Earth
- Have Become More Accurate
- Great Variety
- Mathematically Described by
  - Semi Major axis \( a \)
  - Semi Minor axis \( b \)
  - Flattening \( f \), \( f = (a-b)/a \)
  - Eccentricity \( e \), \( e^2 = f \times (2-f) \)
Typical Ellipsoid Model

- Flattening
- Semi-minor axis: \( b \)
- Semi-major axis: \( a \)
- Semi-minor axis: \( b \)
- Semi-major axis: \( a \)
Ellipsoids

Geoid
Ellipsoidal Shifts

- **Local Ellipsoid**
- **Global Ellipsoid** (WGS 84)
- **Geoid** *(Orthometric Height)*
Ellipsoidal Parameters

Semi-Minor Axis =
Polar Radius = b
(WGS-84 value = 6356752.3142 meters)

Semi-Major Axis =
Equatorial Radius = a
(WGS-84 value = 6378137.0 meters)

Flattening = $f = \frac{a-b}{a}$
(WGS-84 value = 1/298.257223563)

First Eccentricity Squared = $e^2 = 2f - f^2$
(WGS-84 value = 0.0066943799013)
Example of Datum Shifts

There Are Over 280 Active Mapping Datums In The World Today

- Cape Town
- European Datum 1900
- WGS 84
- Australian Geodetic System 1984
- British Ordinance Survey 1936
- Indian Datum
- Tokyo
- 97° 44’25.19” West WGS 84
- 30° 16’ 28.82” North WGS 84
- 1000 Meters

November 8, 2001 Geodesy In Aviation Slide No. 15
Effect of Datum on Aviation

Where the end of the runway is located based on **Local Datum**

Where the aircraft is at the end of the GPS approach procedure using WGS-84 Datum

The Position of the Runway Must Be Moved to Comply with WGS-84 Datum
Since 1985 40% of all Aviation Fatalities Have Resulted from Controlled Flight Into Terrain.

Philip M. Condit
Chairman-CEO, Boeing Corp.

The Position of the Runway Now Conforms to WGS-84

Where the aircraft is at the end of the GPS approach procedure using WGS-84 Datum

Where the end of the runway is located AFTER WGS-84 Survey

36
462 m
Heights

- Present a Major Problem for Global Navigation

- Where Is Height (Elevation) Measured From?
  - Center of the Earth
  - Surface of the Earth
  - Somewhere Else?

- Where is Mean Sea Level (MSL)?
Common Basis For Height

- **Topographic Surface**
  - The Surface We Stand Upon

- **Geoid**
  - Equipotential Surface Based on Gravity
    - Approximates Mean Sea Level

- **Ellipsoid Surface**
  - Mathematical Model for Mapping
  - Usually Local in Nature
    - Based On Local Datum
Geoid Influences

- The Geoid is an Irregular Surface Defined by Gravity Potential
- If Whole Planet Covered With Water, It Would Equal the Geoid Surface (MSL)

Effect of Mass Distribution (extremely exaggerated)
Height Relationships

H = Orthometric Height (h-N)
h = Ellipsoidal Height (H+N)
N = Geoidal Height (Gravity)
GPS Height Reference

- Earth's Surface
- Ellipsoid
- Geoid
Geodial Separations

WGS-84 Geoid Height

From NIMA 10 by 10 Degree Geoid Height Grid
EGM96

- EGM96 is a Spherical Harmonic Model of the Earth's Gravitational Potential
- The NIMA/NASA Geoid Height File Consists of a 0.25 Degree Grid of Point Values in the Tide-free System
- Based on Gravity Measurements
- NIMA Will Assist in Making Gravity Measurements
  - Fiducial Stations
  - Loan Equipment
  - Training

Note that EGM96 applies only to the WGS 84 reference ellipsoid
EGM96-360 Model

30° Mean Gravity Anomalies: EGM96 (Nmax=360)

- 10° North
- 67° West

Longitude
Latitude

-100 -50 0 50 100 mgal

NASA
Ohio State University
Cheju-Do

Cheju Intl. (CJU)
- 33° 30" N
- 126° 29" W
- N = +25.5 meters

\[ H = h - N \]
\[ H = 30m - 25.5m = 4.5m \]
What is WGS 84

- World Geodetic System - 1984
- Provides Global Consistency
  - Earth-Centered
  - Satellite Defined
    - 24 NAVSTAR Satellites
    - 20,200 km Orbits
    - US DOD & DOT Maintained
    - Global Availability
- Adopted by ICAO In 1989
GPS In Geodetic Surveying

Types of Positioning

- **Point positioning (absolute)**
  - Precise Ephemeris Required
  - Removal of Selective Availability (SA) Effects
  - Special Processing Software and Algorithms
    - NIMA’s GASP or JPL’s GIPSY
  - Large Data Sets (Long Observation Times)

- **Relative (Differential) Positioning**
  - Networks Required
    - Geodetic Networks
  - Post Processing of Vectors
    - Least Squares Network Adjustments Required
  - Real Time Kinematic Possible
The GPS Vector:

- **Ground Distance**
- **Geodesic**
- **Station 1**
- **Station 2**
- **Ellipsoid**

**VECTOR**

Direct measurement from Station 1 to Station 2
Purpose of WGS 84 Surveys

- Provide Accurate WGS-84 Survey Data at Airfield
  - Certify Runway & NAVAID Positions
- Locate and Map Obstructions
- Critical for GNSS Systems Such as LAAS
- Need for GPS Approach Design
  - TERPS and PAN-OPS
- Support the Use of Satellite-Based Navigation (GNSS) in the Region
Project Approach

- Develop Work Plan and Schedule
  - Notify Airport and Aviation Officials

- Airport Reconnaissance
  - Consult with Airport Engineers & Security Officials

- Conduct Field Surveys
  - Set Required Monuments
  - GPS and Conventional Surveys
  - Quality Assurance

- Prepare Final Reports and Charts
  - Final Briefing
**Typical Airfield Survey**

- **Site/Area Reconnaissance**
  - Gather Existing Maps, Charts and Control Data
  - Locate or Set Monuments (PACS, SACS & Control)

- **GPS Positioning of PACS**

- **GPS Positioning of SACS**

- **Survey Runway Features**

- **Profile Runway & Taxiways**

- **Locate NAVAIDS**

- **Locate Obstructions**
Surveying Procedures

- PACS and SACS
  - Assistance from NIMA with GPS Post Processing

- Runway Features
  - Runway Ends
  - Touch Down Zone

- Navigation Aids (Visual and Electronic)

- Vertical Obstructions (Obstacles)

- Photo Control
PACS and SACS?

Airfield Permanent Reference Monumentation

- Primary Airport Control Station (PACS)
- Secondary Airport Control Station (SACS)
- WGS-84 Positioned
- Stable, Permanent Monuments
- Visibility,
  - 1000 Meters Apart with Intervisibility for use with Conventional Survey Equipment
- Horizon
  - Interference/Multipath
- Reference Drawings
Sample Reference Drawing

Include All Pertinent Information

- Date, Location, Airport Code, Monument Type, etc.
- Include a Verbal Description of Location

Draw Sketch

- Show Relative Location of Monuments to Features
- Include Measured Reference Ties, Minimum of 3 Ties
- CAD Drawing is Preferred for Clarity, Digital File and Inclusion with GIS

Include Photo of Monument

Description of Geodetic Station

Station Name: PSOMAS
Airport Code: ICAO/IATA
Established By: Name
Location: Brief location description
Date: 1999
Description:
The station is a 50mmØ bronze disk stamped "ICAO/MAR PAC 3 1999" set flush with concrete on top of a large concrete mound.

Sketch:
La Chinita International Airport, Maracaibo, Venezuela
Concrete
Runway
20 m
Asphalt Area
15 m
PAC 3

Photo
Runway Features

Why?
- Needed for GPS Approach and LAAS

What?
- Ends
  - Should be Monumented
- Corners
- Thresholds & Stopways
- Vertical Profile of the Centerline

How?
- Conventional or GPS Surveys
  - Total Station or Stop and Go GPS
NAVAIDS

- A Position, and Sometimes an Elevation, Shall Be Determined for the Selected Electronic NAVAIDS Associated With the Airport or Adjacent Airspace.

- Why?
  - Transition, Needed to Compute and Prepare Flight Charts

- What?
  - Electronic Devices such as VOR, RADAR and ILS

- How?
  - GPS or Conventional Surveying
**Location Techniques**

Location by Theodolite Angles

*Control Points Must Be Close.*

*Complex Trigonometric Computations Needed.*

Location by Reflectorless (LIDAR) Total Station.

*One Point Needed, Back Sight to Any Known Point. Record Positions (X,Y,Z) Directly Into Data Collector.*

= GPS Positioned Control Point
Vertical Obstructions

An Obstruction, for This Section, Is Any Object That Penetrates an Obstruction Identification Surface (OIS). It Shall Be the Highest Object Within the Area

What?

- Physical Features
- Topographic Features
- Man-made Features

How?

- Surveys vs. Imagery
- Economy vs. Utility
Approach Surface 1

Side View of Approach Surface

- 50:1 Approach Slope Surface
- Horizontal Surface
  - 152 meters above lowest runway end
- Runway
  - 60 m
- End of Runway
  - 7,620 m ft
- 5,300 m
- 12,980 m (7NM)
- 152 m
Approach Surface-2

Top View of Approach Surface

Runway

Primary Surface

Center Line of Runway

12,980 m (7nm)

300 m

60 m

98°

4,233 m

13,199 m

60 m

12,980 m (7nm)
Approach Surface-3

End View of Runway, Showing the Primary/Approach Transitional Surface

- Primary Transitional Surface
  - 7:1 Slope
  - 45 m above lowest runway end

- Runway End
- Primary Surface Centerline

- 625 m
- 300 m
- 320 m

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Approach Surface-4

Top View of Conical/Outer Horizontal Transitional Surface Obstructions

- Conical Surface, 20:1 Slope
- Inner Horizontal Surface
- Primary/Approach Transitional Surface
- Inner Horizontal Surface
- Primary/Approach Transitional Surface
- Conical Surface, 20:1 Slope
- Outer Horizontal Surface
Collection Model 3-D

Obstruction Identification Surface (OIS)

Not to Scale
It All Comes Together

Profile Runway

Survey Obstructions as Specified

Should Be Intervisible

NAVAIDS

Thresholds & Corners

PACS

Airport Bldg.
Photogrammetric Mapping

- **Location of Obstacles**
  - Airfield DEM

- **Photo Control**
  - Sharply Defined Corners
  - Bigger Is Better
  - High Contrast
  - Ideal Distribution
  - GPS Locations Relative to Airfield Control Stations
Satellite Imaging

The Use of Satellite Imaging Will Be of Great Value in Near Future

1-Meter Resolution Image of Taipai Airport Approach from IKONOS 2 Satellite

Space Imaging Corp
Survey Work Flow

1. Research
2. Reconnaissance
3. Logistics
4. PACS
5. Features & Profiles
6. SACS
7. Photo Control
8. NAVAIDS
9. Obstructions
10. Documentation
11. Check Plots & Q.C.
12. Deliver to Client
Project Deliverables

- 1 Primary & 3-4 Secondary WGS-84 Control Stations
- X,Y,Z Positions on Runway Thresholds & Centerline
- Location of NAVAIDS & Obstructions
- Photo Control
- ICAO (Type “A”) Obstacle Chart
- ICAO Aerodrome Chart
- Final Report
Accuracy & Precision

Accuracy

The Accuracy Requirements Are Expressed (Root Sum Square of the Accumulated Process Errors), Per Component (Latitude, Longitude, and Ellipsoid Height), 90% Confidence Region, to Include the Accuracy of the Recognized WGS 84 Fiducial Station.

Precision

The Precision Requirements Are Expressed (Root Sum Square of the Accumulated Process Errors Less the Absolute Accuracy Estimate of the PACS) Per Component (Latitude, Longitude, and Ellipsoid Height), 90% Confidence Region, With Respect to the PACS.
### Specifications (ICAO)

**Precision Requirements (expressed in meters) Relative to PACS**

<table>
<thead>
<tr>
<th>Points Of Interest</th>
<th>Rel. ($\phi/\lambda$)</th>
<th>Rel. (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Airport Control Station (PACS)</td>
<td>0.6*</td>
<td>0.6*</td>
</tr>
<tr>
<td>Secondary Airport Control Station (SACS)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Runway Ends</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Airport Reference Point (ARP)</td>
<td>30</td>
<td>N/R</td>
</tr>
<tr>
<td>Touch Down Zone Elevation (TDZE)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Threshold Ends</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Overrun (stopway) Ends</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

* Denotes Absolute Position
### Points Of Interest

<table>
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<th>Points Of Interest</th>
<th>Rel. (φ/λ)</th>
<th>Rel. (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Runway Profile:</strong> At least 4 surveyed points</td>
<td>N/R</td>
<td>0.3</td>
</tr>
<tr>
<td>along the runway surface are required in all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>cases. The points should include the runway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ends and 2 other points located as to divide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the runway into 3 approximately equal sections.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Additionally, if the gradient between any two</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surveyed points departs the actual runway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surface by more than 0.3 meter, supplemental</td>
<td></td>
<td></td>
</tr>
<tr>
<td>points shall be established until the standard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>is met.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Route Surveillance Radar</td>
<td>100</td>
<td>N/R</td>
</tr>
<tr>
<td>Airport Surveillance Radar</td>
<td>100</td>
<td>N/R</td>
</tr>
</tbody>
</table>
## Specifications (ICAO) - 3

**Precision Requirements (expressed in meters) Relative to PACS**

<table>
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<th>Points Of Interest</th>
<th>Rel. ($\phi/\lambda$)</th>
<th>Rel. (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument Landing System (ILS)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Localizer</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Middle Marker</td>
<td>3</td>
<td>N/R</td>
</tr>
<tr>
<td>Outer Marker</td>
<td>3</td>
<td>N/R</td>
</tr>
<tr>
<td>Glide Slope (GS)</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Distance Measuring Equipment (DME)</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td>Photo Identifiable Points</td>
<td>N/R</td>
<td>N/R</td>
</tr>
<tr>
<td>Obstacles (Highest Obstructions)</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>
QUALITY ASURANCE IN AIRFIELD SURVEYS

“Quality Assurance Depends on Management, Process, Documentation and Qualified, Well Trained Staff”

William Edwards Deming (1900-1993)
5 Steps to Quality Assurance

1. Project Delivery Plan
2. Standards
3. Tasks & Responsibilities
4. Documentation
5. Qualified Staff
**GIS For Airports**

- **Airfield Positions and Features Will Be Managed By GIS**
  - NIMA is Moving To This Technology
  - Spatial Data Management
  - Digital Map and Chart Production
  - Periodic Updates

- **Other Uses For Airport GIS**
  - Facilities Management
  - Ground Traffic Management
  - Approach Design
  - Noise Contour Mapping
  - 3-D Visualizations
Airfields In A GIS
Community Noise Equivalent Levels (CNEL) Impact on Jurisdictions
QUESTIONS & DISCUSSION