WAAS/LPV Flight Inspection

The Importance of Database Integrity and Standardization

Presented to: IFIS 2008

By: Gary A. Flynn, P.E.

Organization: Federal Aviation Administration,
Aviation System Standards, USA

Date: June 24, 2008

Topics

- Introduction – Timeline & Equipage
- Background – Technical Audit
- Challenge 1: Vertical Guidance and TCH
- Challenge 2: Database Integrity & Standardization

Introduction

- **Timeline**
  - 1999: AVN begins WAAS R&D work using experimental equipment
  - 2004: AVN has established procedures for inspecting WAAS/LPV approaches
  - 2004: AVN's WAAS/LPV inspection program is short-lived, Threshold Crossing Height (TCH) values are unreasonable
  - 2005: AVN begins in-depth technical audit of WAAS/LPV inspection program

Introduction

- **Equipage**
  - Six Lear 60 Aircraft
  - Collins Multi-Mode Receiver (MMR) with WAAS
  - Differential GPS (auxiliary truth system)
  - Upgraded Flight Management System (Universal)
  - Flight Inspection Software Changes

Introduction

MMR Installation in Lear 60

MMR

Introduction

Lear 60 Flight Inspection Workstation

Introduction

Engineering Lab – Test Station

Background

- **Experience Gained Analyzing F.I. Data for NASA MSBLS**
  - Verified both the sample-by-sample results and analytical results
  - Extremely complex effort (position transformations, extrapolations, etc.)

- **Approached by WAAS/LPV F.I. Technicians**
  - Unrealistic Threshold Crossing Heights (TCH)
  - Preliminary discussions raised concerns

Background

- **Preliminary Review Raised Issues**
  - TCH not included in pass/fail criteria
  - Method for calculating TCH not well documented
  - TCH results inconsistent & unreasonable
- **Decision**
  - Convinced AVN management to halt WAAS/LPV inspection until issues resolved
  - Highest priority given to resolving issues
  - Concentrated on vertical profile, not so much on lateral

1: Vertical Guidance & TCH

- **Why Check WAAS Guidance?**
  - Unlikely WAAS signal would be a problem
  - WAAS guidance Threshold Crossing Height (TCH) is an excellent indicator of accuracy and integrity of the procedure and supporting data
- **TCH – Simple Definition**
  - Vertical distance from runway surface to WAAS/LPV guidance path at threshold

1: Vertical Guidance & TCH

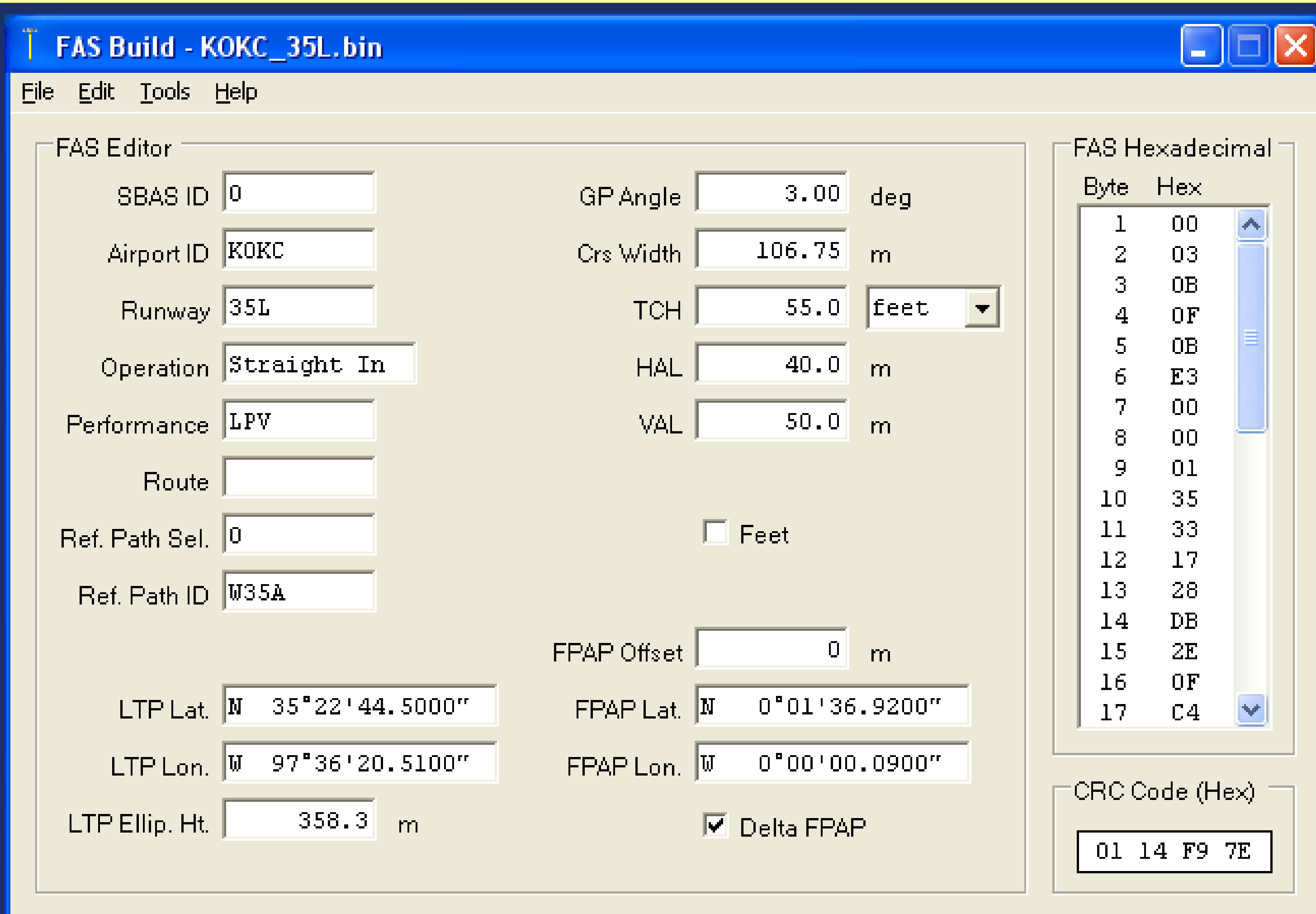
- **ILS**
  - Relatively immune to survey errors
- **WAAS/LPV**
  - Complex solution
  - Runway survey data*
  - Airborne database: Final Approach Segment (FAS) data block definition*
  - WAAS ground station surveys*

* Has associated reference datum

1: Vertical Guidance & TCH

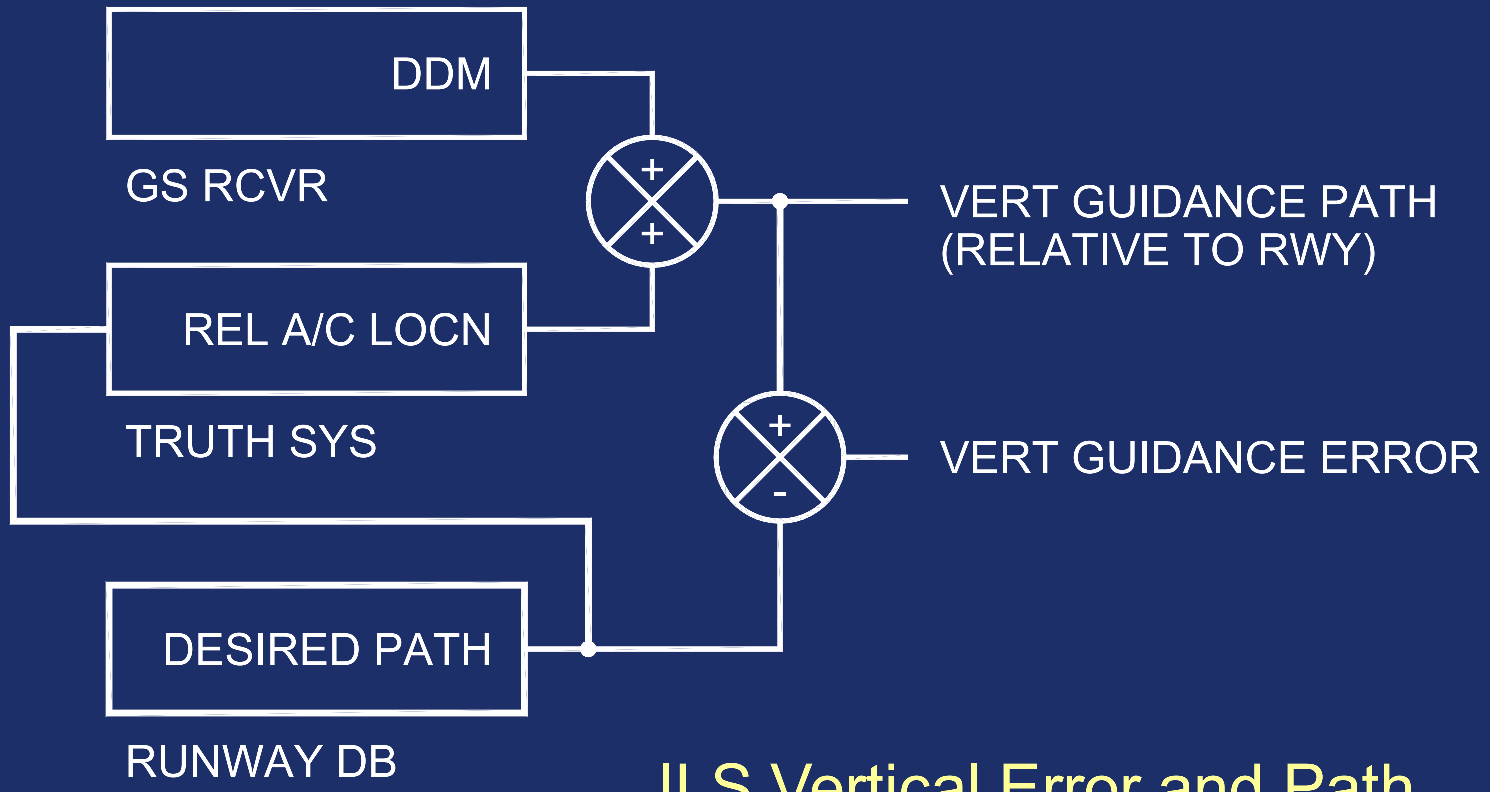
- **Methodology**
  - Create WAAS/LPV vertical guidance and check in a manner similar to ILS glideslope
  - Just as for ILS, assume all error is due to WAAS/LPV solution, none due to truth system
  - Use Final Approach Segment (FAS) data block specification to define desired path (see FAS Build screen shot)

1: Vertical Guidance & TCH



FAS Build Screen Shot

1: Vertical Guidance & TCH



ILS Vertical Error and Path

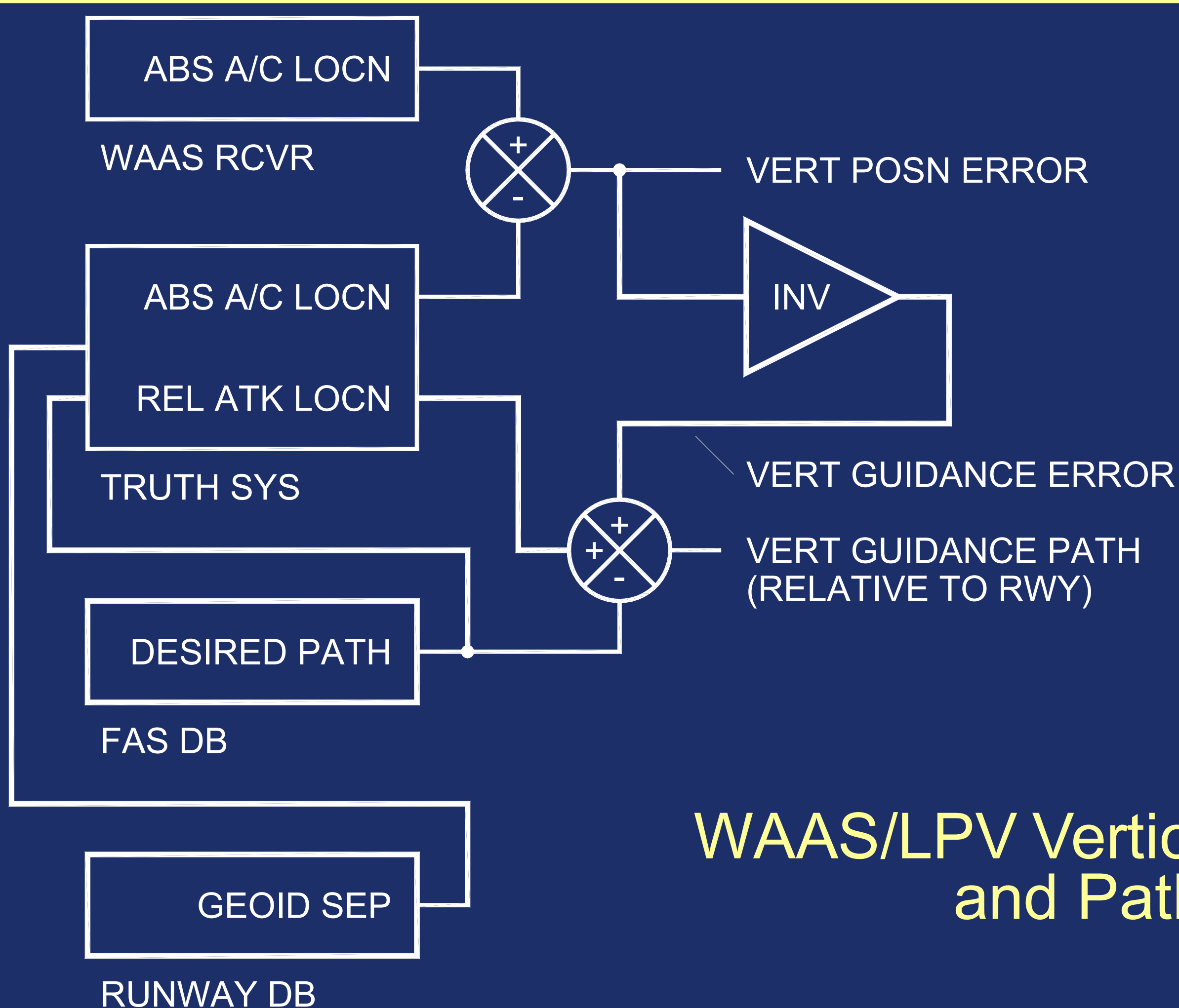
1: Vertical Guidance & TCH

- **WAAS Guidance Error vs. Position Error**
  - WAAS guidance error is same magnitude as position error but opposite in polarity
  - Sample below assumes that WAAS is reporting altitude 10 feet below actual

Case: WAAS Vertical Position Error vs. Guidance Error

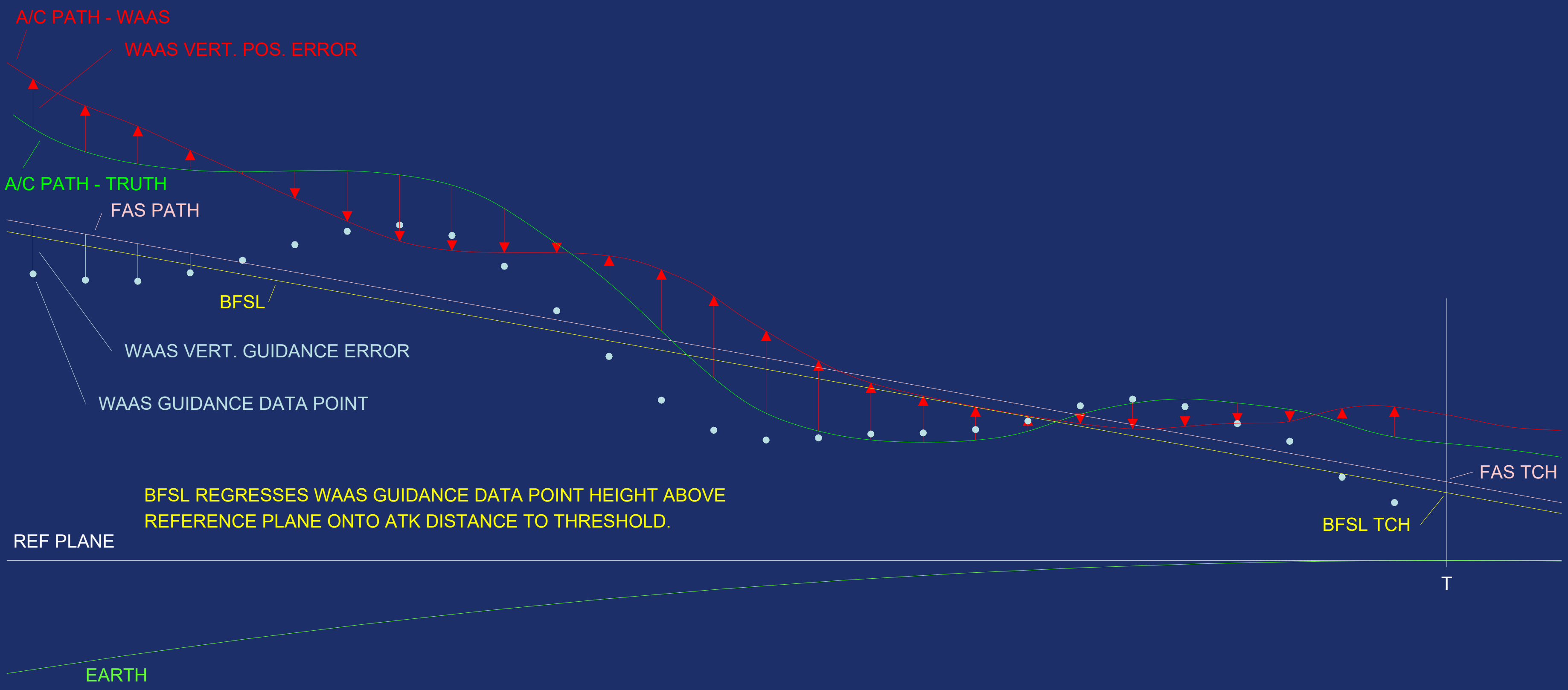
Actual Aircraft Position	On path
WAAS Reported Position	10 ft below path
WAAS Guidance	10 ft above path

1: Vertical Guidance & TCH



WAAS/LPV Vertical Error and Path

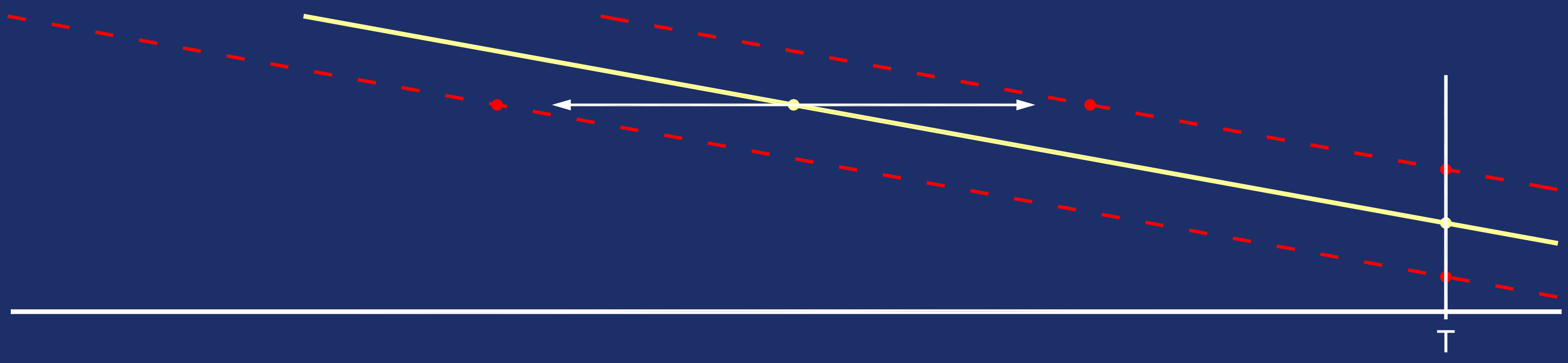
1: Vertical Guidance & TCH



WAAS Vertical Guidance Data Points

1: Vertical Guidance & TCH

- **Compensating for ATK Error**
  - For a 3° glideslope, a 20-foot ATK error will produce 1 foot of vertical error
  - Two methods for compensation are described in IFIS paper

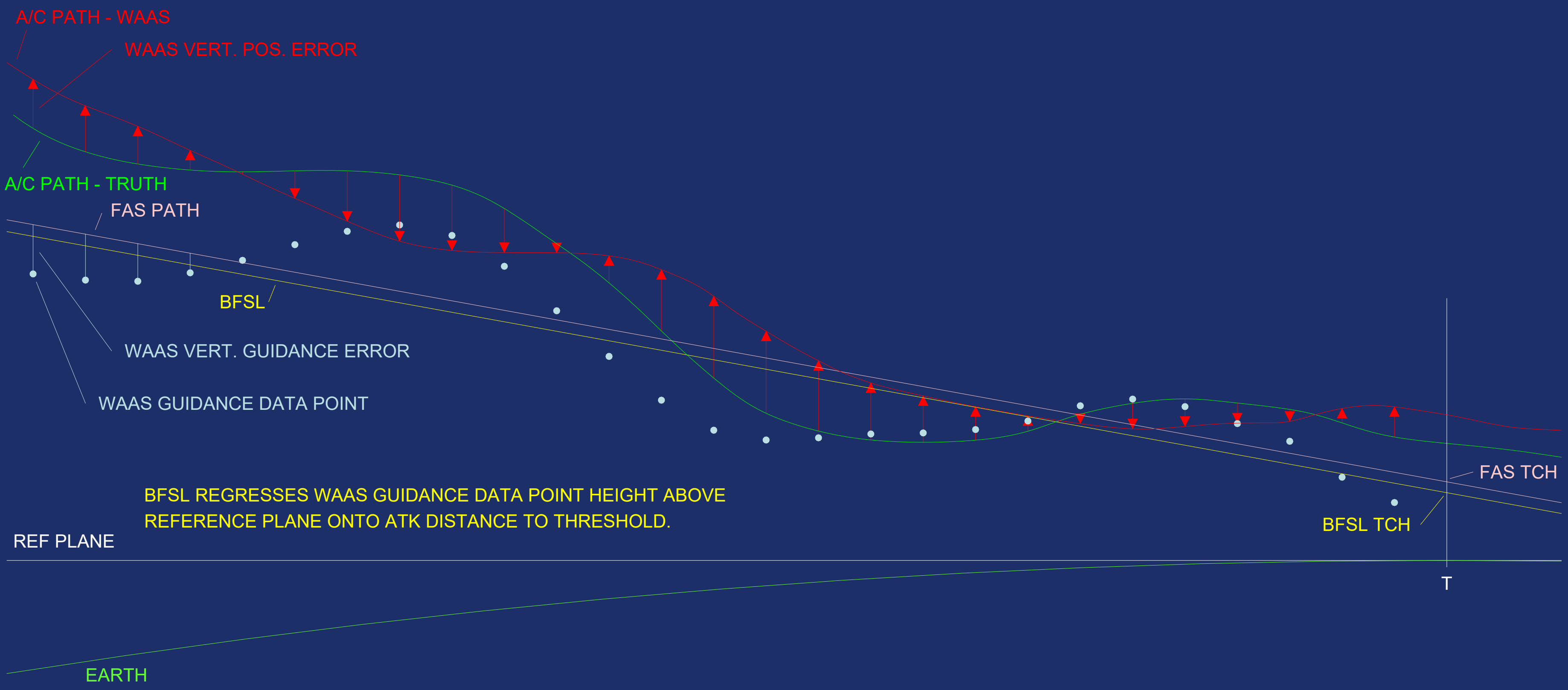


ATK Error affects TCH

1: Vertical Guidance & TCH

- **Best Fit Straight Line**
  - Linear regression of vertical guidance path from FAF to Threshold
  - Produces GPA and TCH
  - Using multiple data points reduces anomalous results
  - GPA will typically match FAS

1: Vertical Guidance & TCH



WAAS Vertical Guidance Data Points

1: Vertical Guidance & TCH

The End

...of Part 1

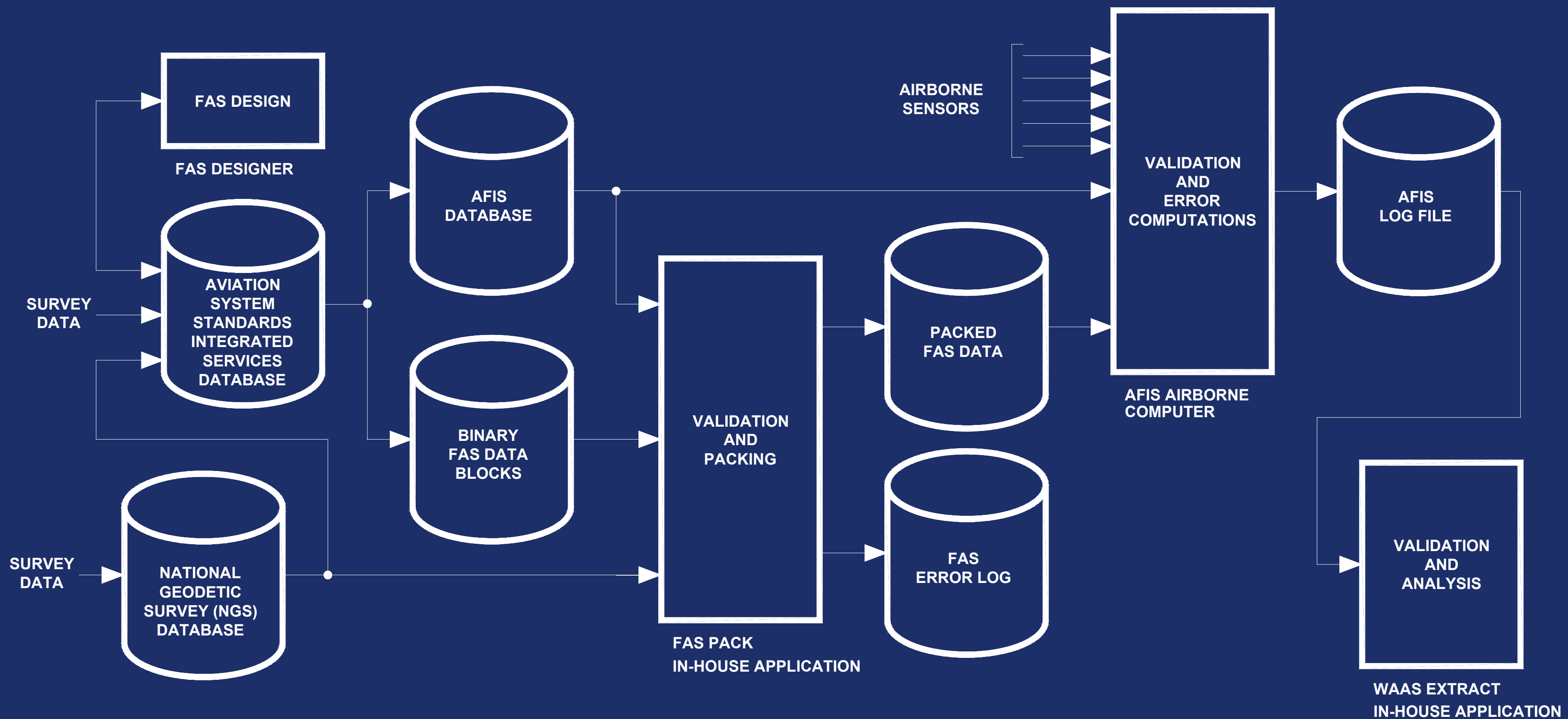
2: DB Integrity & Standardization

- **Influence of Data**
  - ILS - local geometry only
  - WAAS/LPV - Affected by:
    - Runway survey data
    - FAS data block definition
    - GPS/WAAS signal (WAAS Reference Station surveys)
  - Must ensure data is accurate
  - Must ensure all relate to same geodetic datum

2: DB Integrity & Standardization

- **Engineering Tools**
  - FAS Pack: Checks FAS data block files before flight (also used to package multiple data blocks into single file)
  - WAAS Extract: Analyzes AFIS log files & validates AFIS results

2: DB Integrity & Standardization

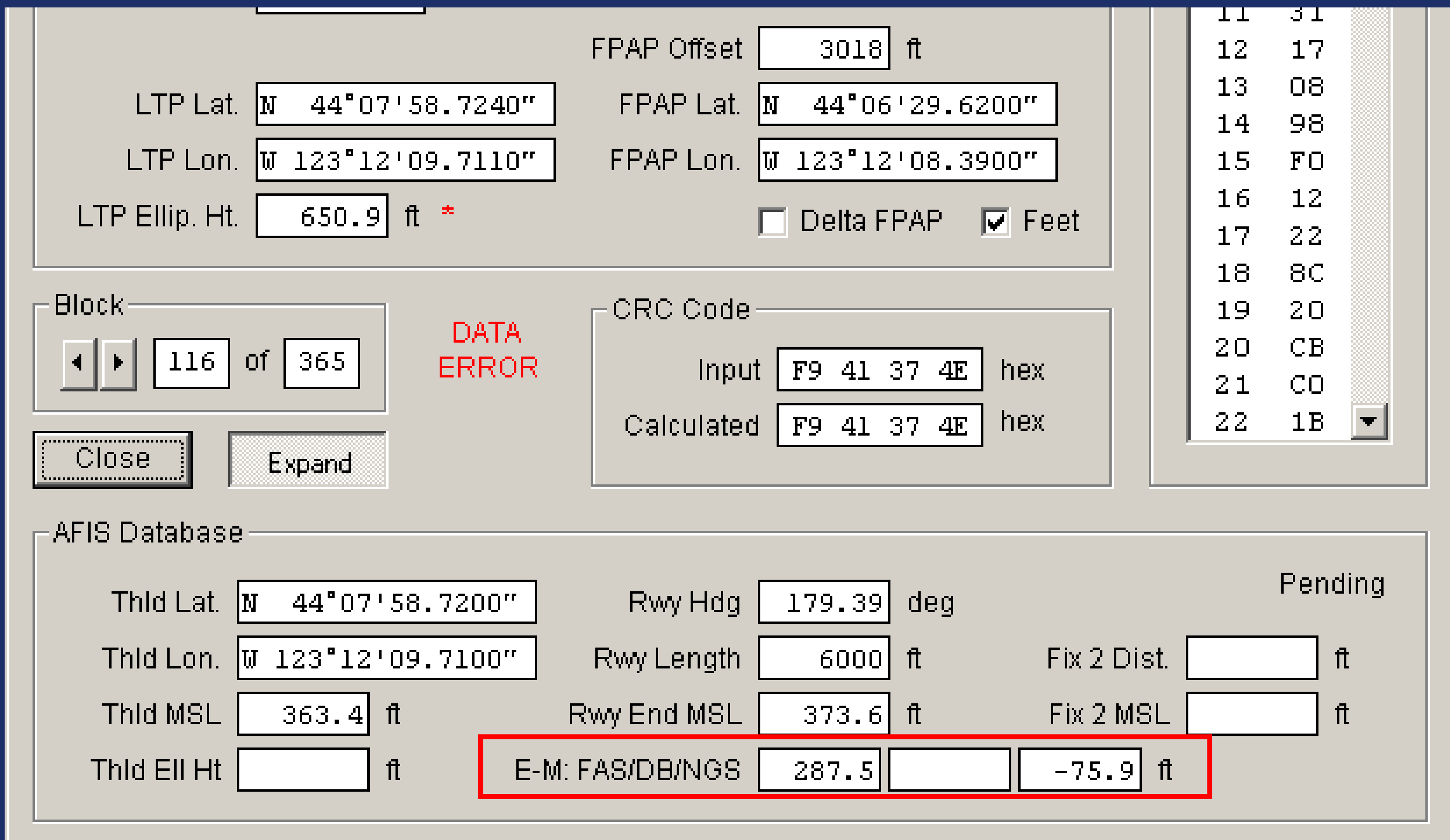


Data Flow -WAAS LPV Flight Inspection

2: DB Integrity & Standardization

- **Errors Discovered**
  - FAS data block design or data entry
  - Survey data
  - Transfer of survey data into database
  - Latent errors associated with runway database
  - Runway database filter algorithm
  - Differences in geodetic datum

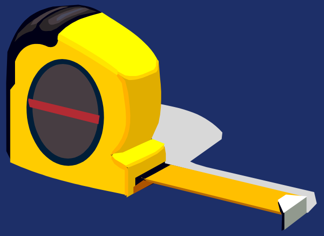
2: DB Integrity & Standardization



363 Ft Vertical Error at Threshold (FAS Pack Tool)

2: DB Integrity & Standardization

- **"Four-Foot Offset"**
  - Persistent TCH bias during technical audit
  - Averaged about 4 feet
  - Changed somewhat with geographic location
  - Many tests performed to identify source:
    - Multiple truth systems
    - Post-flight analysis
    - Static aircraft and laboratory tests
    - Use of multiple WAAS receivers



2: DB Integrity & Standardization

- **"Four-Foot Offset" (Continued)**
  - Stumbled upon answer (phone conversation with NGS)
  - North American Datum 1983 (NAD83) vs. World Geodetic Survey 1984 (WGS-84)
    - Initially equivalent
    - WGS-84 datum has been shifted about 2 meters
  - RTCA DO-229C specifies WGS-84 for FAS data
  - Continue to use NAD83 ellipsoidal height when creating FAS data blocks

2: DB Integrity & Standardization

Ellipsoidal Height Data References

Runway Survey	Typically NAD83
FAS Data Block	Same as Runway
WAAS Guidance (Reference Stations)	WGS-84

NAD83 vs. WGS-84 Vertical Differences

Los Angeles, California	2.3 ft
Oklahoma City, Oklahoma	3.7 ft
Daytona Beach, Florida	5.0 ft

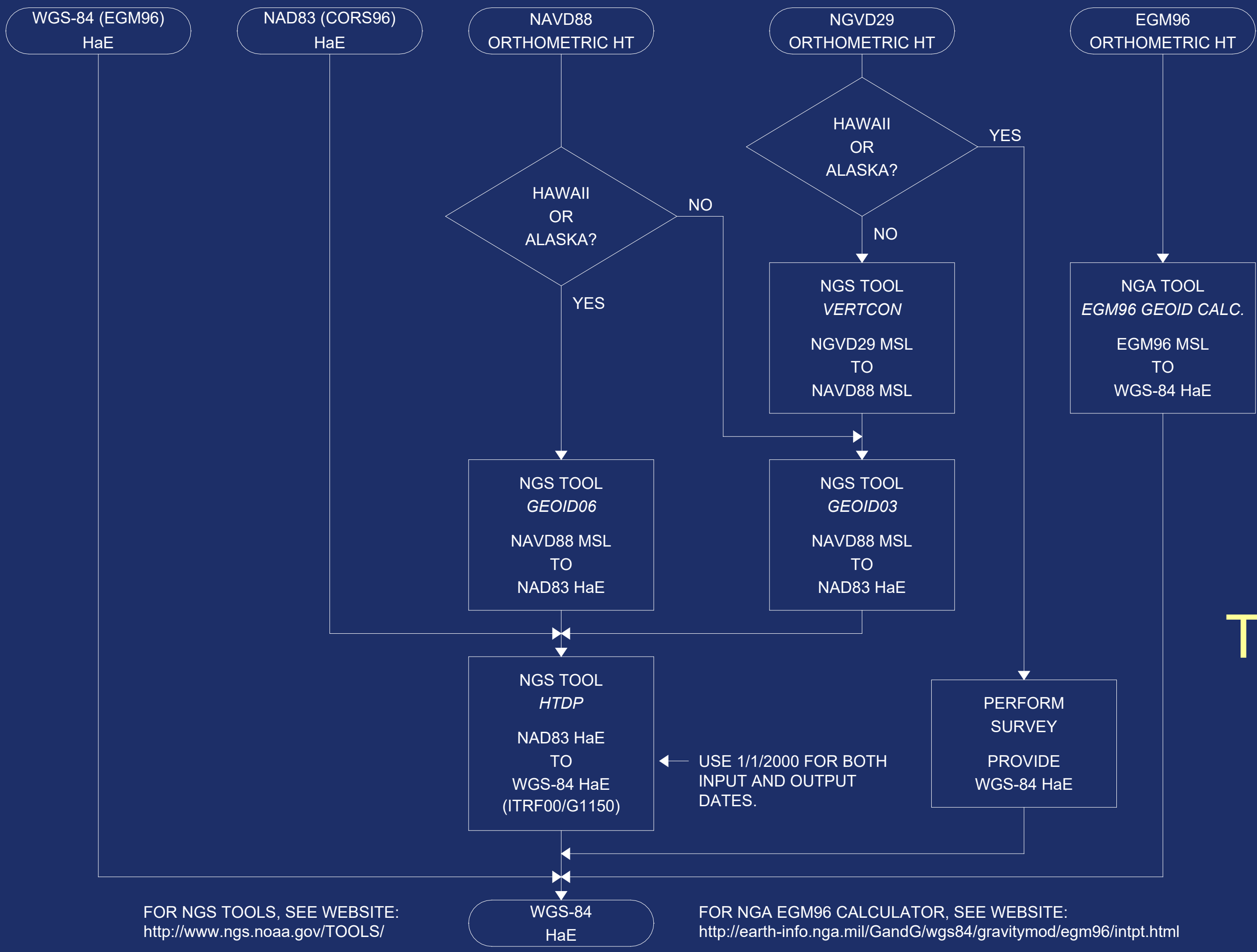
2: DB Integrity & Standardization

- **Other Survey References**
  - Many WAAS/LPV approaches based upon legacy, orthometric (MSL) coordinate systems
    - North America Vertical Datum 1988 (NAVD88)
    - National Geodetic Vertical Datum 1929 (NGVD29)
  - Tools provided by NGS and NGA convert orthometric height (MSL) to ellipsoidal height (HaE)

MSL: Mean Sea Level (Orthometric Height)

HaE: Height above Ellipsoid (Ellipsoidal Height)

2: DB Integrity & Standardization



Mixed Datum Altitude Transformations

Conclusions

- **Conclusions**
  - Imperative to establish exactly what is being checked (and pass/fail criteria)
  - BFSL TCH provides a good figure of merit for the WAAS/LPV approach
  - Database accuracy and standardization are larger contributors to WAAS/LPV approach problems than the actual signal in space
  - Due to the susceptibility of WAAS/LPV to survey errors and the multiplicity of opportunities for errors to enter the development process, it is imperative that an end-to-end check be performed

The End

Questions?