NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

December 9, 2015

Multiple Electronic Devices

Specialist's Factual Report
by Bill Tuccio, Ph.D.

1. EVENT

Location:	Bloomington, Illinois
Date:	April 7, 2015
Aircraft:	Cessna 414A
Registration:	N789UP
Operator:	Make It Happen Aviation, LLC
NTSB Number:	CEN15FA190

On April 7, 2015, about 0006 central daylight time (CDT), a Cessna model 414A twin-engine airplane, N789UP, was substantially damaged when it collided with terrain following a loss of control during an instrument approach to Central Illinois Regional Airport (BMI), Bloomington, Illinois. The airline transport pilot and six passengers were fatally injured. The airplane was owned by and registered to Make It Happen Aviation, LLC, and was operated by the pilot under the provisions of 14 *Code of Federal Regulations* Part 91 while on an instrument flight rules (IFR) flight plan. Night instrument meteorological conditions prevailed for the cross-country flight that departed Indianapolis International Airport (IND), Indianapolis, Indiana, at 2307 CDT.

2. DETAILS OF INVESTIGATION

The National Transportation Safety Board (NTSB) Vehicle Recorder Division received the following devices:

Device 1:	Shadin Altitude Alert System
Device 1 Serial Number:	2473
Device 2:	Shadin Fuel Flow Indicator
Device 2 Serial Number:	8218
Device 3:	Garmin GNS 530W
Device 3 Serial Number:	78410737
Device 4:	Garmin GNS 430W
Device 4 Serial Number:	97103703
Device 5:	Garmin GMA 347 Audio Panel
Device 5 Serial Number:	Unknown

Device 6: Avidyne EX600 Multi-Function Display (MFD)
Device 6 Serial Number: 93217898

Device 7: Sandel SN3500 Navigation Indicator
Device 7 Serial Number: 1058

2.1. Shadin Altitude Alert System Device Description

The Shadin Altitude Alert System (part number AMS 2000) alerts the pilot when approaching or deviating from a target altitude. Alerts may be set for decision height or minimum descent altitude on instrument approaches. Altitude information is received from the transponder's altitude encoder. Last programmed values may be retained by the unit, though no historical recording of altitude exists.

2.1.1. Shadin Altitude Alert System Data Recovery

Upon arrival at the Vehicle Recorder Division, an exterior examination revealed the unit had not sustained any damage (see figure 1). External power was applied and the unit started normally. All display modes were examined.

Figure 1. Shadin Altitude Alert System.

2.1.2. Shadin Altitude Alert System Data Description

All altitude screens displayed blank values. Figure 2 is an example display for decision height. It could not be determined if the blank values were due to the device not being used by the pilot or if the values were not retained between power cycles.

Figure 2. Shadin Altitude Alert System example display of decision height.

2.2. Shadin Fuel Flow Indicator Device Description

The Shadin Fuel Flow Indicator is a digital fuel management system designed to provide fuel management information under real-time flight conditions to the flight crew. The unit is connected to engine fuel flow transducers. The unit is capable of transmitting fuel information to certain GPS receivers for additional calculations and display of fuel management data. The unit can display engine fuel flow, fuel used, fuel remaining, and endurance.

The unit does not interface with an aircraft's fuel quantity indicating system. The unit requires the flight crew to enter the initial fuel on board the aircraft. All calculations and data provided by the unit are based on fuel flow.

2.2.1. Shadin Fuel Flow Indicator Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an exterior examination revealed the unit had sustained significant impact damage, as shown in figure 3. An internal inspection revealed the non-volatile memory[1] chip was cracked, as shown in figure 4.

The chip was examined using a computed tomography (CT) scan, as shown in figure 5. The CT scan showed the interior wire bonds were intact; however, the status of the chip die could not be determined. Attempts were made to read the chip using an EEPROM reader; however, these attempts were unsuccessful. The chip was then put in a surrogate device, and an error was received as shown in figure 6.

[1] Non-volatile memory is memory that does not need power to retain information.

Figure 3. Shadin Fuel Flow Indicator as received.

Figure 4. Shadin Fuel Flow Indicator cracked non-volatile memory chip.

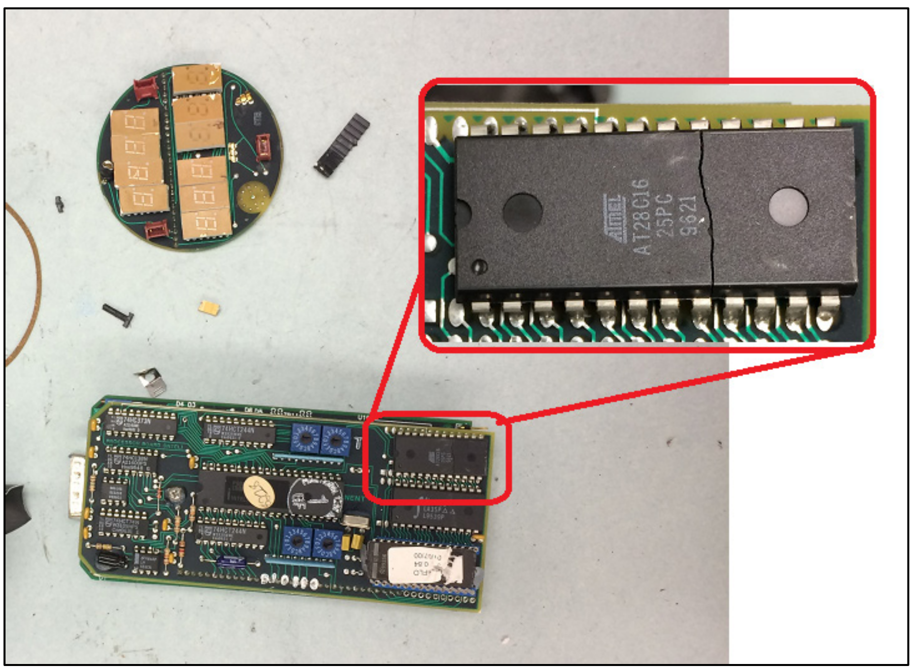


Figure 5. CT scan of chip internals.

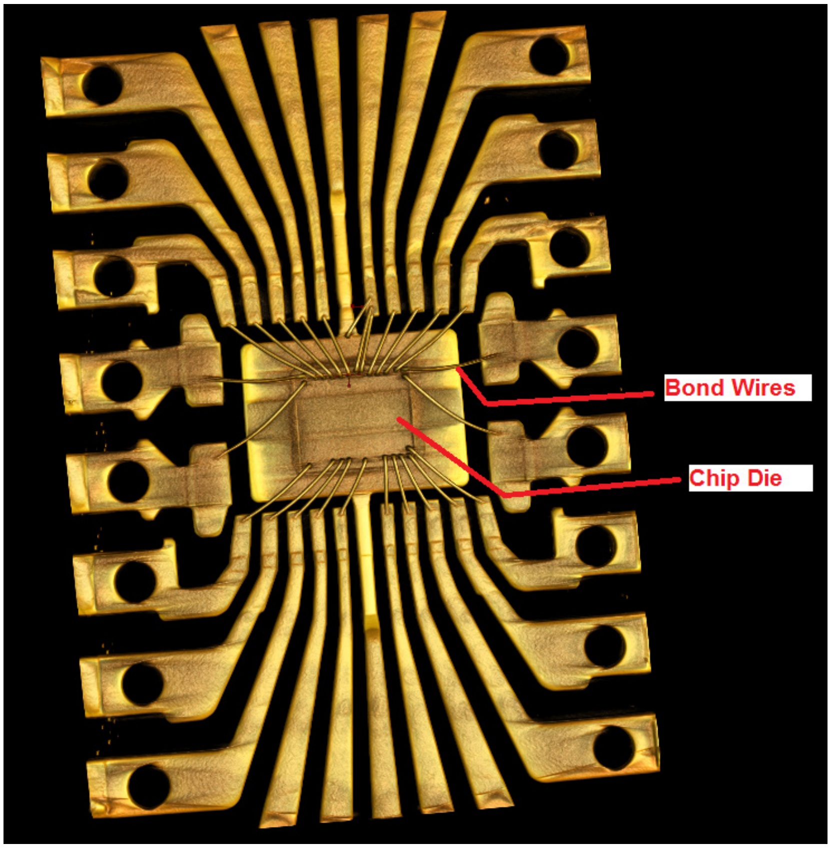
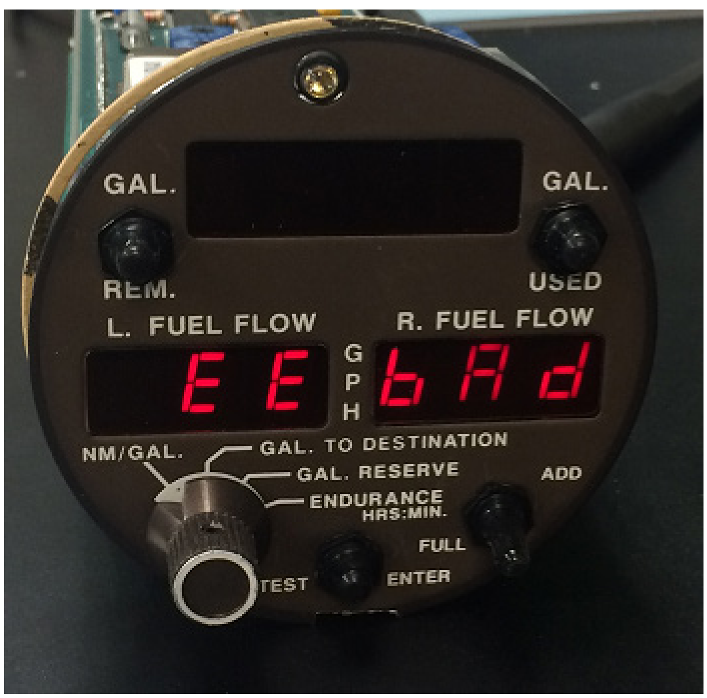


Figure 6. Readout with accident chip in surrogate.



2.2.2. Shadin Fuel Flow Indicator Data Description

No data was recovered from the Shadin fuel flow indicator.

2.3. Garmin GNS 530W and 430W Device Description

The Garmin Models GNS 530W/430W are panel-mounted NAV/COM/GPS receivers featuring a liquid crystal (LCD) display and offering navigation and communication capabilities, along with precision and non-precision approach certification in the IFR environment. The unit has a slot for a Jeppesen database (front-loading data card) containing all airports, VORs, NDBs, intersections, Approach, STAR/SIDs and SUA information. A flight plan composed of multiple waypoints, including user-defined waypoints, can be programmed in the unit. However, no provision has been made to record and store position information within the unit. Data related to frequency settings and last CDI VLOC/GPS mode selection are stored in non-volatile memory and may be read from the front panel display upon power-up. There are no provisions for downloading stored data to a PC. An internal button-battery is used to back-up power to the internal memory and real-time clock during those periods when main power is removed.

When connected to a Sandel SN3500 navigation indicator (see Section 2.6 of this report), localizer and glideslope deviation and validity information are provided to the Sandel SN3500 via ARINC 429 Label 173 and 174 words, respectively.

2.3.1. Garmin GNS 530 Glideslope Valid Flag Logic

According to the Garmin 530 Installation Manual (190-00181-02 rev T), the conditions which cause the Glideslope flag to indicate invalid are any of the following conditions[2]:

a. When the level of a standard deviation test signal produces 50% or less of standard deflection of the deviation indicator.[3]
b. In the absence of 150Hz modulation[4].
c. In the absence of 90Hz modulation.
d. In the absence of both 90Hz and 150Hz modulation.
e. In the absence of RF[5].

2.3.2. Garmin GNS 530W and 430W Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an exterior examination revealed both units had sustained significant impact damage, as shown in figure 7. The front-loading IFR database cards were undamaged and read in an NTSB Garmin 430. The screens and interface button panels on each unit were replaced and each unit powered on successfully; allowing last frequency and CDI mode to be examined.

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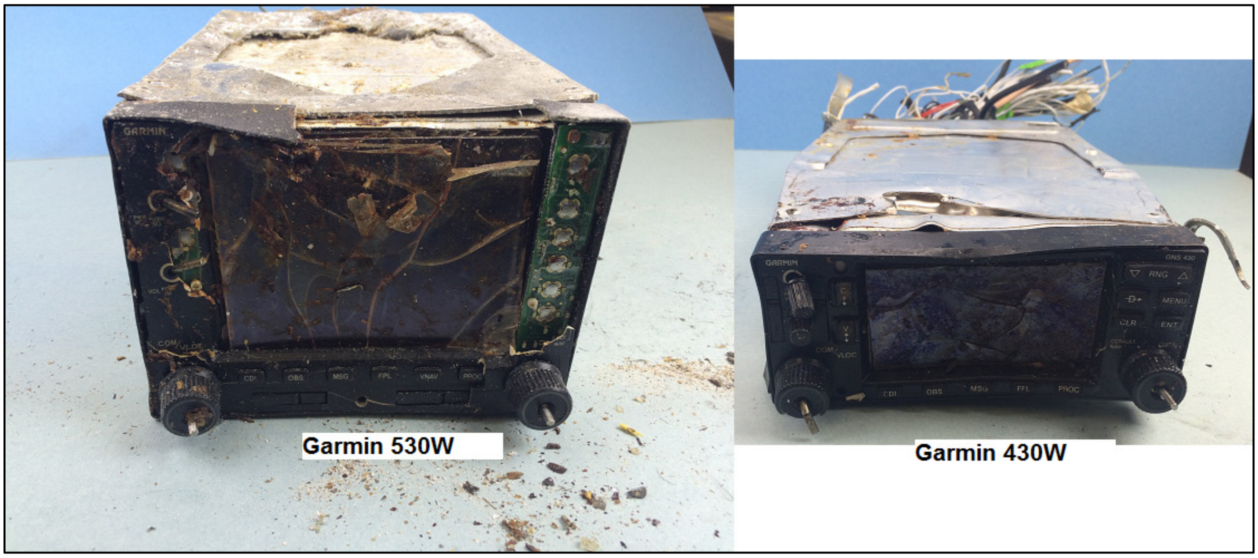
[2] Items (a) through (e) are directly quoted from the Garmin 530 Installation Manual, 190-00181-02 rev T; footnotes are added for elaboration
[3] The test signal condition is only used for ground-based/maintenance testing.
[4] A glideslope signal consists of two intersecting radio signals modulated at 90Hz and 150Hz (FAA Instrument Flying Handbook).
[5] RF means radio frequency.

Figure 7. Garmin 530W and 430W as received.



2.3.3. Garmin GNS 530W and 430W Data Description

The IFR database on both cards expired on April 30, 2015. Table 1 summarizes frequencies and CDI modes recovered from each unit, and figure 8 shows the units powered on with repaired screens. In figure 8, the navigation display area is redacted as the displayed information was related to the repair process and not the accident flight.

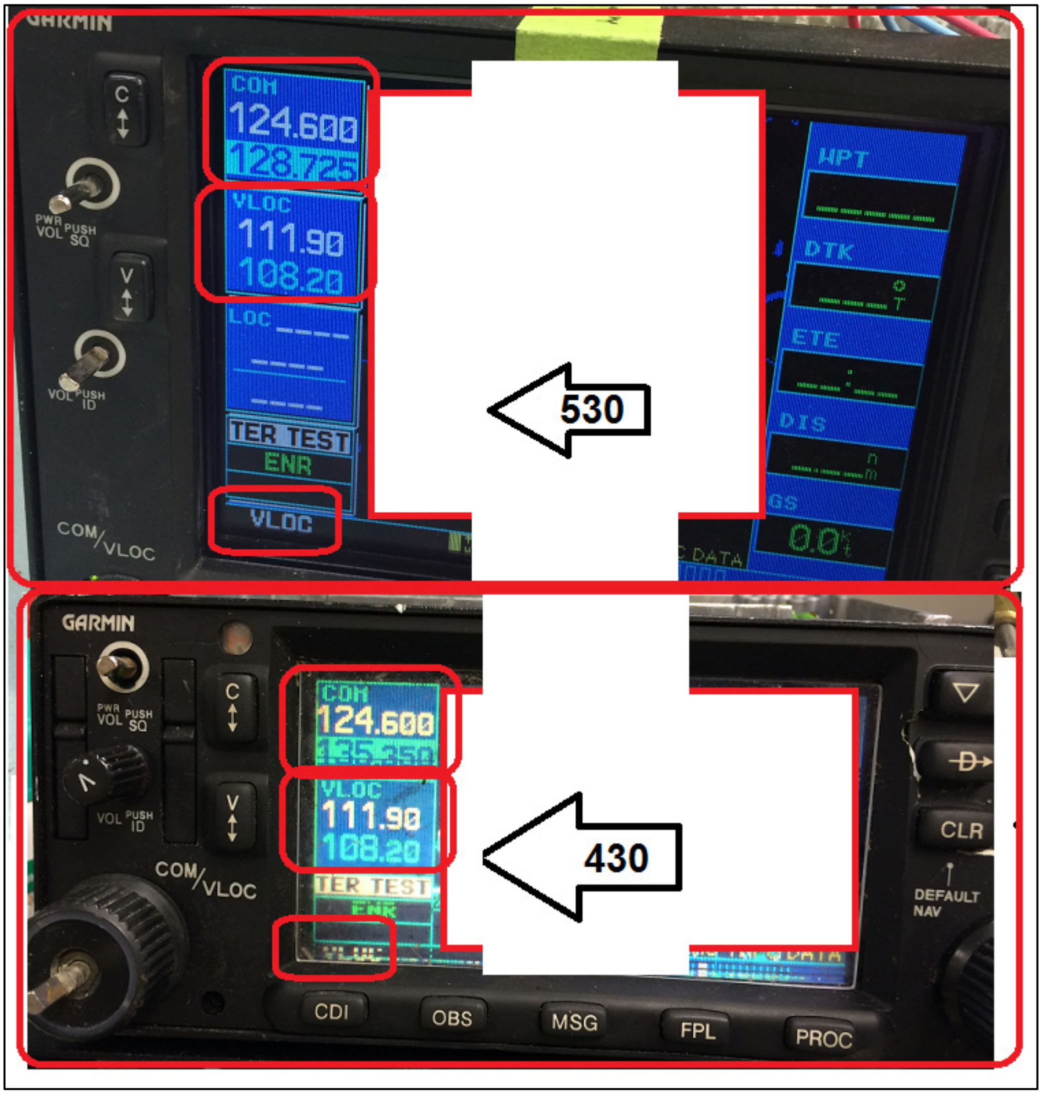
Table 1. Selected frequency/mode information from Garmin 530W and 430W.

Data	Garmin 530W	Garmin 430W
Active COM frequency	124.600	124.600
Standby COM frequency	128.725	135.350
Active NAV frequency	111.90	111.90
Standby NAV frequency	108.20	108.20
CDI VLOC/GPS mode	VLOC	VLOC

According to the FAA Airport Facility Directory:

- The BMI tower frequency and, after hours, the common traffic advisory frequency (CTAF) (also used for pilot controlled lighting) was 124.6.
- The automatic terminal information service (ATIS) frequency for BMI was 135.35.
- This interlocked BMI ILS frequency to runways 2 and 20 was 111.9.
- The BMI VOR/DME frequency was 108.2.
- Peoria approach control frequency was 128.725.

Figure 8. Garmin 530W/430W with front screen/button interface replaced.



2.4. Garmin GMA 347 Audio Panel Device Description

The Garmin GMA 347 is an audio selection panel and may be enabled to record a short duration of radio transmissions for playback by the pilot; any such recordings are in volatile memory and are erased after power is removed from the device.

2.4.1. Garmin GMA 347 Audio Panel Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an exterior examination revealed the unit had sustained significant impact damage, as shown in figure 9. Since the unit does not record any information, no effort was made to repair the unit.

Figure 9. Garmin GMA 347 as received.

2.4.2. Garmin GMA 347 Audio Panel Data Description

No information was retrieved.

2.5. Avidyne EX600 MFD Device Description

The Avidyne EX600 MFD is a multi-function display capable of displaying navigation and weather information. According to the manufacturer, the unit is capable of recording weather data history; however, there is no way to determine if the weather data was viewed by the pilot. Further, on power-up the unit retains last settings used by the pilot.

2.5.1. Avidyne EX600 MFD Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an exterior examination revealed the unit had sustained minor impact damage, as shown in figure 10. Given the nature of the recorded information, no attempt was made to recover information.

Figure 10. Avidyne EX600 as received.

2.5.2. Avidyne EX600 Data Description

No information was retrieved.

2.6. Sandel SN3500 Navigation Indicator Device Description

The Sandel SN3500 Navigation Indicator is an electronic horizontal situation indicator (EHSI). The unit performs the functions of a traditional HSI and radio magnetic indicator (RMI)[6], including: heading indicator, course deviation indicator, glideslope indicator, RMI functions, and a heading bug interfaced to an optional autopilot. The EHSI extends traditional HSI functions to include (depending on installation): RMI navigation to GPS waypoints, weather display of lightning and datalink weather, and traffic display.

Data is recorded once per second (1 Hz) to a 24 megabyte circular buffer for manufacturer diagnostic purposes; depending on configuration and power cycles, this equates to about 6 to 12 hours of recorded data. The recorded data derives from two separate channels internal to the unit, channel 1 and channel 2; no time information is recorded by the unit. The data may be downloaded and decoded by the manufacturer.

2.6.1. Sandel SN3500 Glideslope Display Logic

According to Sandel, an ARINC 429[7] input provided glideslope deviation and validity information. Figure 11 provides an excerpt from the Sandel SN3500 EHSI Pilot's Guide (82005-PG-E, page 9-2), showing that a glideslope invalid input to the SN3500 results

[6] A traditional RMI presents a course to a ground based navigation aid superimposed over a compass card (FAA Pilot's Handbook of Aeronautical Knowledge, FAA-H-8083-25A).
[7] ARINC 429 is a data formatting standard used by avionics.

in a red “X” displayed through the glideslope scale and removal of the glideslope pointer (i.e., the glideslope pointer is replaced by the red “X”).

Figure 11. Excerpt from Sandel SN3500 Pilot's Guide.

GS (glideslope) flag		Large red “X” through glideslope scale (VDI), glideslope pointer is not displayed.

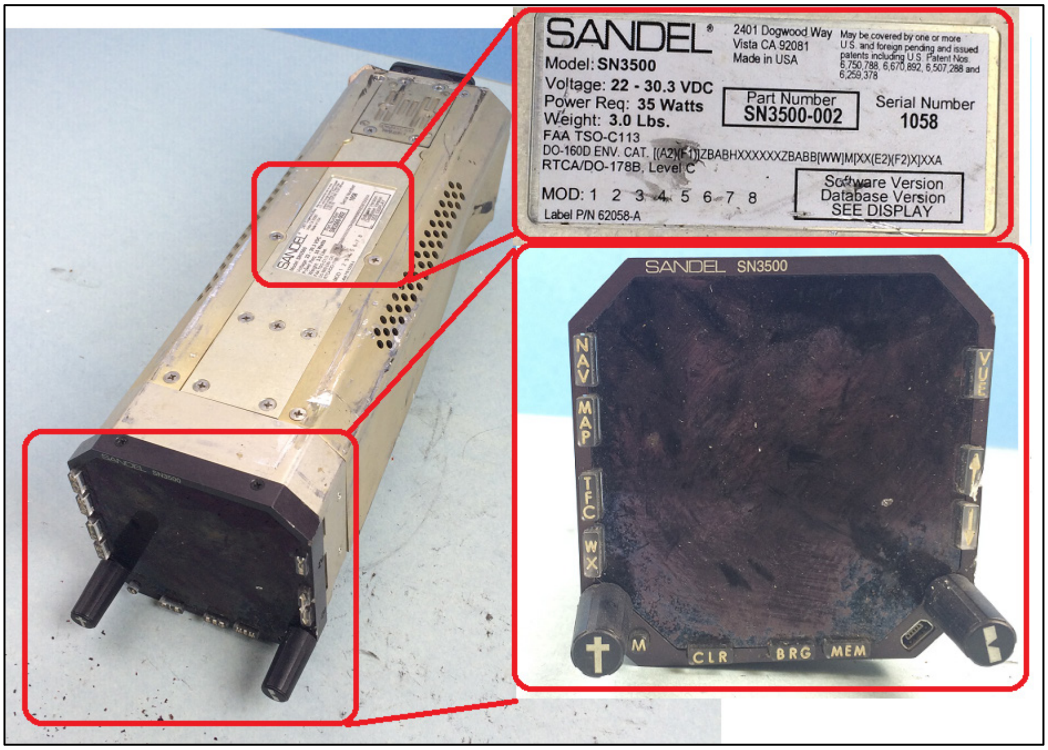
2.6.2. Sandel SN3500 Installation Specific Configuration

According to the Investigator-in-Charge, the accident aircraft was configured such that the Garmin 530W was the channel 1 input, and the Garmin 430W was the channel 2 input. According to Sandel, channel 1 was the input from navigation unit 1 and channel 2 was the input from navigation unit 2. Therefore, in the remainder of this report, when referring to navigation signals, “channel” and “nav” are used interchangeably to refer to navigation signal 1 and navigation signal 2.

2.6.3. Sandel SN3500 Navigation Indicator Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an exterior examination revealed the unit had sustained minor impact damage, as shown in figure 12. Due to the impact damage, the unit was sent to the manufacturer for downloading and decode of the information.

Figure 12. Sandel SN3500 as received (datatag and front of unit, expanded views).



2.6.4. Sandel SN3500 Navigation Indicator Data Description

Table 2 summarizes the content of each SN3500 recorded log. Logs 02, 03, 05, 07, and 09 were power-ups while the aircraft was on the ground and did not contain pertinent data.

Table 2. Sandel SN3500 index of recordings.

Log Number	Departure	Arrival	Date	Notes
Log00	IND	BMI	4/6-4/7, 2015	Accident Flight
Log01	?	BMI	4/1/2015	Oldest data, partial recording
Log04	BMI	MDW	4/2/2015	
Log06	MDW	BMI	4/3/2015	
Log08	BMI	IND	4/6/2015	

Table 3 lists SN3500 parameters verified and provided in this report. All values were provided by the manufacturer in the engineering units indicated. According to the manufacturer, “GSDev_GS” and “GSDev_NAV” derive from the same source and were thus redundant for a given channel[8].

[8] On Channel 1, the redundant glideslope deviations (“GSDev_GS” and “GSDev_NAV”) are both recorded by the software; on Channel 2, only GSDev_NAV is recorded. According to the manufacturer, the redundancy, as well as the difference in behavior between Channel 1 and 2, is an artifact of the recording algorithm.

Table 3. Parameters used in this report.

Parameter and Units	Parameter Description
Date# (mm/dd/yy)	Date of data point (timezone not determined)
Groundspeed# (kts)	Ground Speed
Groundspeed_V# (discrete)	Ground Speed Valid ("V" for valid)
FlightRec# (discrete)	Log Number (0, 1, 4, 6, or 8)
GSDev_GS# (DDMs)	Glideslope Deviation "GS"
GSDev_GS_V# (discrete)	Glideslope Deviation "GS" Valid ("V" for valid)
GSDev_NAV# (DDMs)	Glideslope Deviation "NAV"
GSDev_NAV_V# (discrete)	Glideslope Deviation "NAV" Valid ("V" for valid)
ILS_Tune# (discrete)	Discrete value either: "VOR Mode" or "ILS Mode"
ILS_Tune_V# (discrete)	ILS_Tune Discrete Valid ("V" for valid)
Lat# (deg)	Latitude
Lat_V# (discrete)	Latitude Valid ("V" for valid)
LocDev#[9] (DDMs)[10]	Localizer Deviation
LocDev_V# (discrete)	Localizer Deviation Valid ("V" for valid)
Long# (deg)	Longitude
Long_V# (discrete)	Longitude Valid ("V" for valid)
MagHDG_V1 (deg)	Magnetic Heading from Directional Gyro Valid ("V" for valid)
MagHDG_V2 (deg)	Magnetic Heading from Fluxgate Valid ("V" for valid)
MagHDG1 (deg)	Magnetic Heading from Directional Gyro
MagHDG2 (deg)	Magnetic Heading from Fluxgate
MemoryHdg1 (deg)	Gyro Stabilized Correction to MagHDG2
TRK# (deg)	Ground Track (magnetic or true not determined)
TRK_V# (discrete)	Ground Track ("V" for valid)

Note: deg means degrees; kts means knots.

2.6.5. Sandel SN3500 Navigation Timing and Correlation

Time recorded by the Sandel unit was elapsed time since the start of the power cycle for each log file. In this report, all log files were concatenated with ranges as shown in table 4. The times shown in table 4 are used for the remainder of this report.

Table 4. Sandel SN3500 time ranges.

Log File	Start Time (seconds)	End Time (seconds)
Log00	0	4,118
Log01	4,119	5,338
Log04	5,541	8,669
Log06	8,672	11,354
Log 08	11,357	15,311

2.6.6. Sandel SN3500 Navigation Description of Data

Figures 13 through 21 were created using recorded data from the Sandel SN3500. Google Earth was used to overlay the data on satellite imagery. The weather, season, and lighting conditions in Google Earth are not necessarily representative of the conditions at the time of the accident.

[9] Each parameter is suffixed with a "1" or "2," indicating channel 1 or 2, respectively.
[10] DDM means difference in depth of modulation (FAA Order 8200.1C, U.S. Flight Inspection Manual) and is the "percentage modulation of the larger signal minus the percentage modulation of the smaller signal."

Figure 13 provides an overview of all recorded flights. The accident flight was the last recorded flight from IND to BMI.

Figures 14 through 18 compare parametric localizer and glideslope deviations to Google Earth overlaid flight paths[11] for all recorded flights. Collectively these figures help relate parametric sign conventions to geographic meaning and also allow a comparison of localizer and glideslope usage on prior flights. Table 5 summarizes observations from the five figures. The sign convention of the glideslope could not be unambiguously determined, given the lack of altitude information.

Table 5. Summary of localizer and glideslope deviations.

Figure/Log/Airport	Localizer	Glideslope
14/01/BMI	Nav 1 & Nav 2 both ILS mode and valid; positive (+) was left of course	Nav 1 & Nav 2 both achieved a valid state; first valid state occurred about 3.4nm from approach end of the runway (1.1 nm after EGROW outer marker)
15/04/MDW	Nav 1 & Nav 2 both ILS mode and valid; due to multiple parallel runways, sign could not be determined	Nav 1 & Nav 2 both achieved a valid state
16/06/BMI	Only Nav 1 in ILS mode and valid; negative (-) was right of course	Only Nav 1 in ILS mode and achieved a valid state
17/08/IND	Nav 1 & Nav 2 both ILS mode and valid; negative (-) was right of course	Nav 1 and Nav 2 both achieved a valid state; however, the valid state was achieved about 0.6 nm from the approach end of the runway.
18/00/BMI	Nav 1 & Nav 2 both ILS mode and valid; positive (+) was left of course	Nav 1 and Nav 2 never achieved a valid state

Figure 19 shows the flight path overlaid on the planview portion of the FAA ILS Runway 20 approach procedure. The aircraft intercepted the final approach course inside OLIDE intersection. By the outer marker (EGROW), the aircraft was slightly right of the approach course and continued on the right side until just before the inner marker, at which time the aircraft path deviated nearly 90 degrees to the left.

Figures 20 and 21 show plots of available parameters for the accident that were not already plotted previously. Figure 20 shows the aircraft departure and enroute portions, consistent with the ground track shown in figures 13 and 18. At about 3,990 elapsed time, the groundspeed began to decrease from about 130 kts to 65 kts in 22 seconds as MemoryHdg1 remained relatively constant at about 170 degrees.

[11] Flight paths in Google Earth used latitude and longitude information recorded by the Sandel SN3500.

From about 4,012 to 4,035 elapsed time, the ground speed once again fluctuated, and towards the end of this fluctuation, the MemoryHdg1 began to turn towards the left. By 4,046 elapsed time, MemoryHdg1 had reached 69 degrees.

From 4,046 until the end of the recording at 4,118, the groundspeed fluctuated from 110 kts, to 54 kts, then to 125 kts, followed by a final deceleration that continued until the end of the recording.

From 4,105 until the end of the recording, MemoryHdg1 continued in a left turn of more than 360 degrees.

Tabular data used to generate figures 13 through 21 are included as attachment 1. This attachment is provided in electronic comma-delimited (.CSV) format.

Figure 13. Overview of all Sandel SN3500 recorded flights.

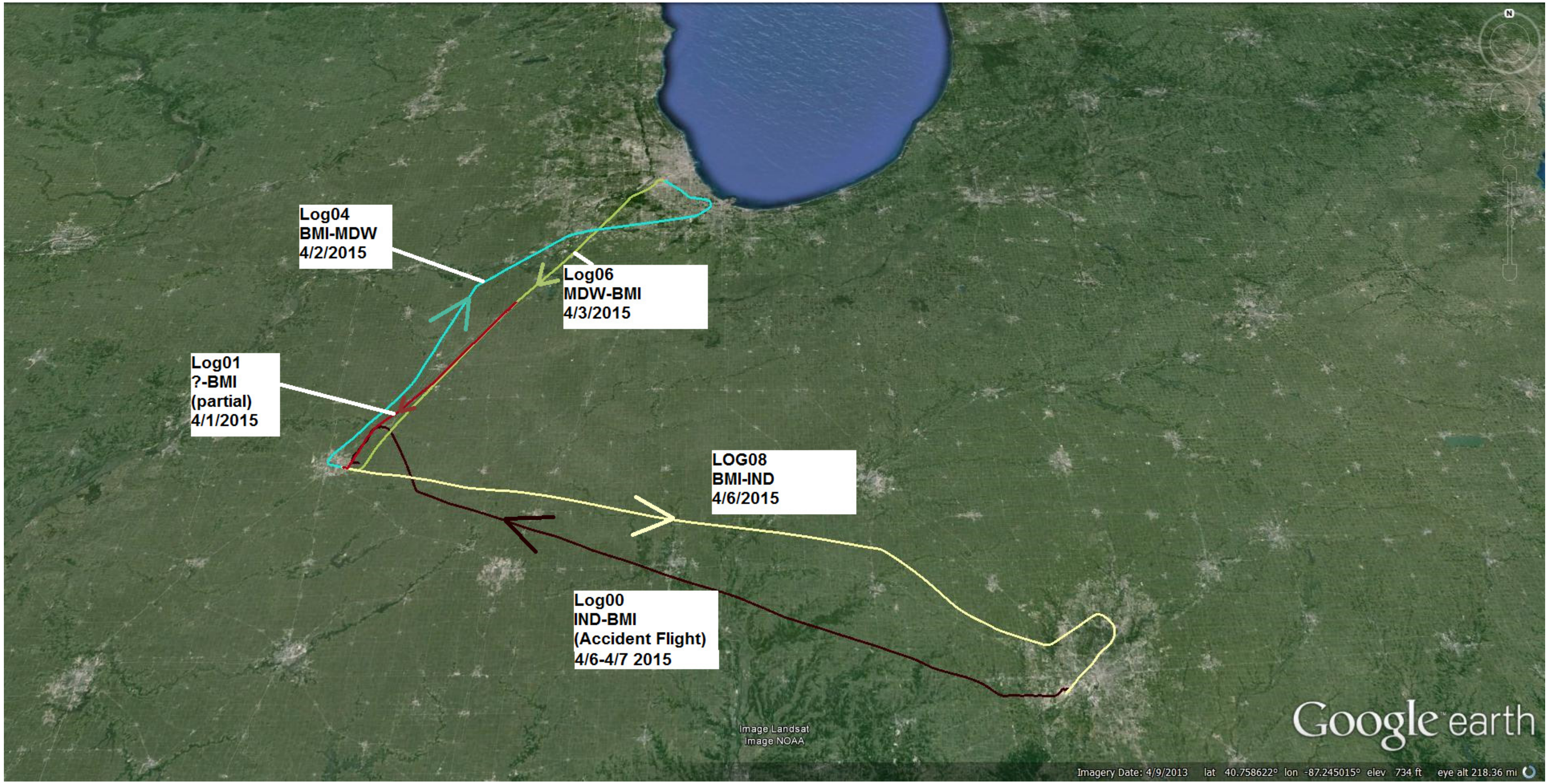
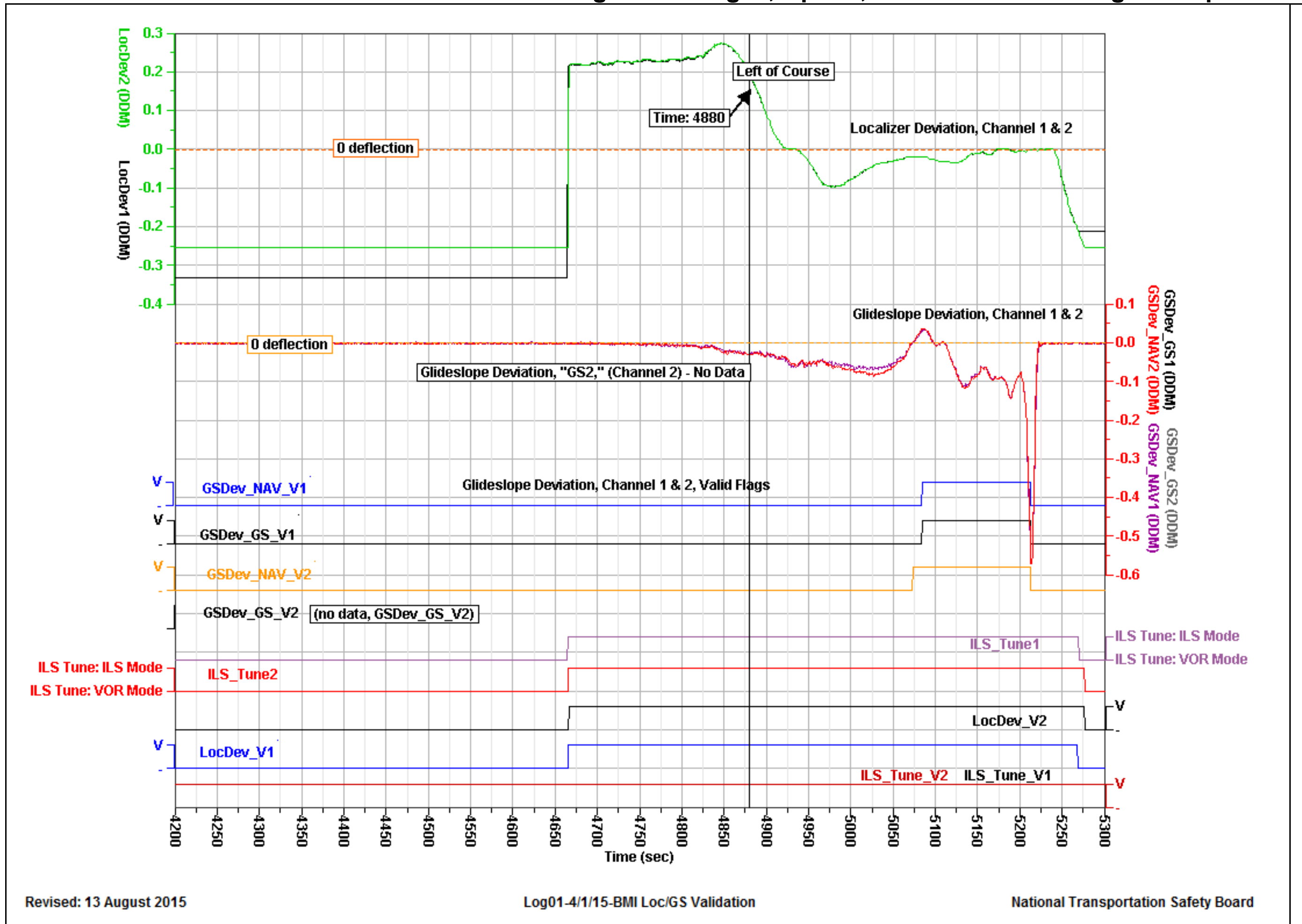


Figure 14. Log01, April 1, 2015 - localizer and glideslope deviations compared to Google Earth overlay.



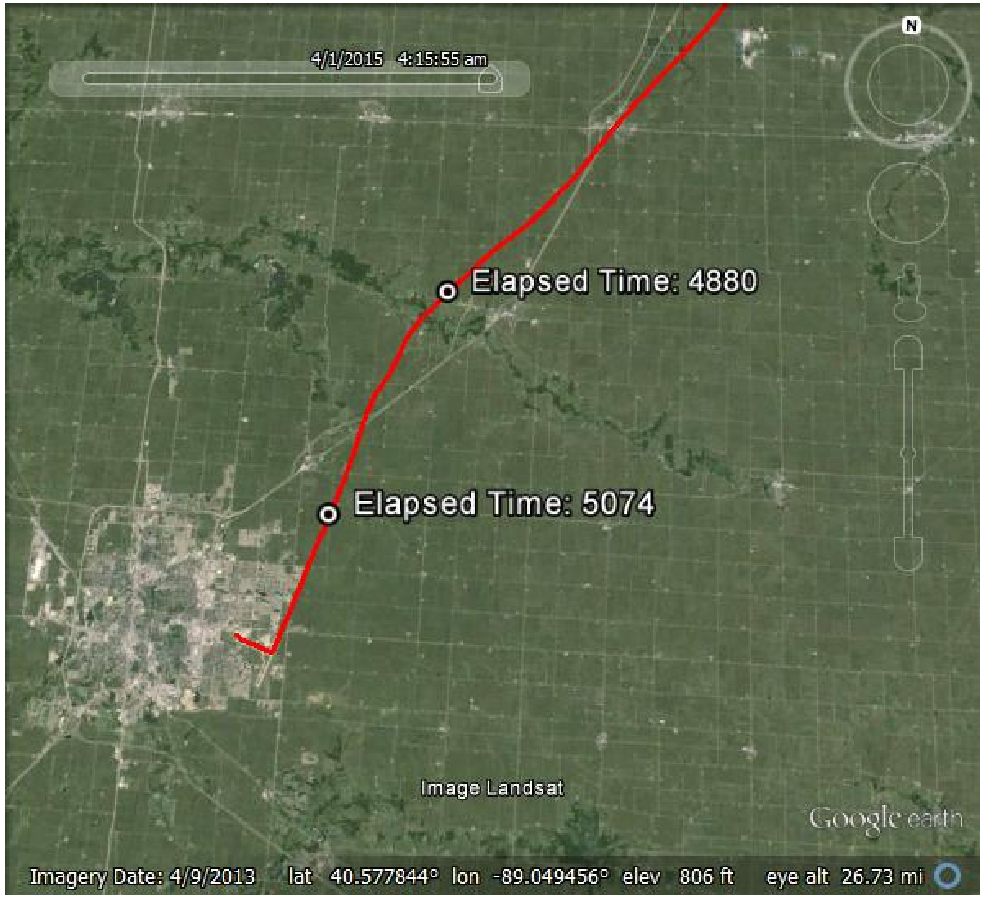


Figure 15. Log04, April 2, 2015 - localizer and glideslope deviations compared to Google Earth overlay.

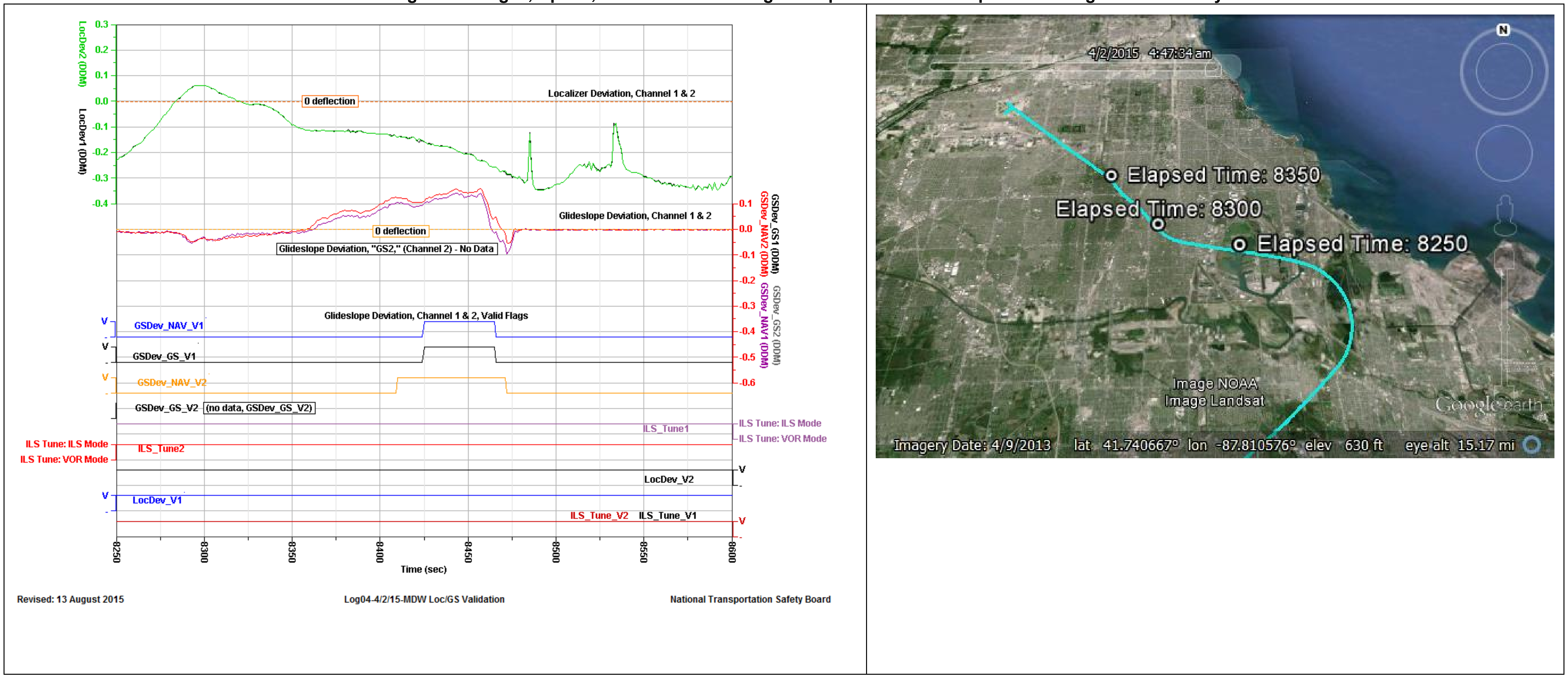


Figure 16. Log06, April 3, 2015 - localizer and glideslope deviations compared to Google Earth overlay.

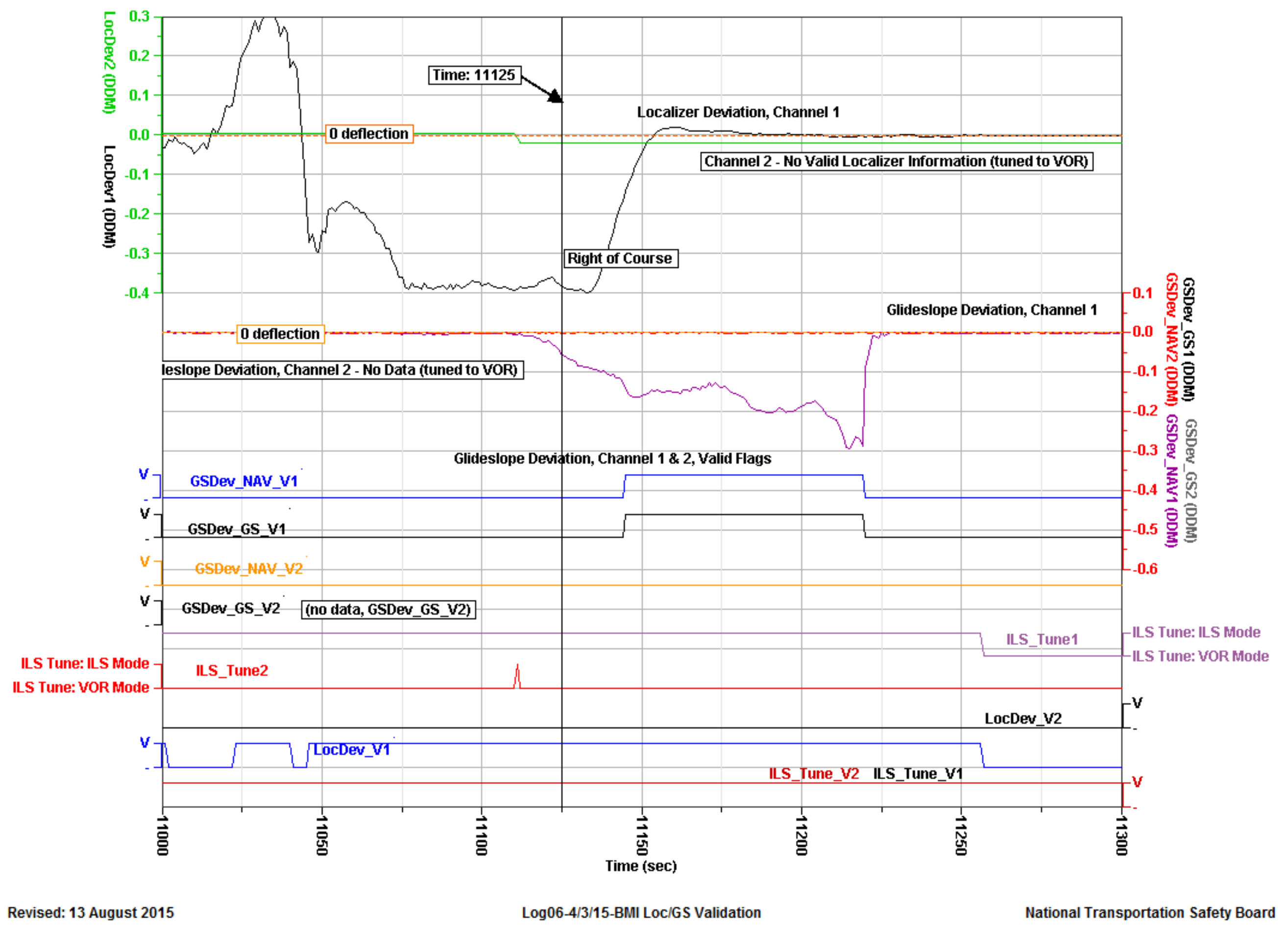
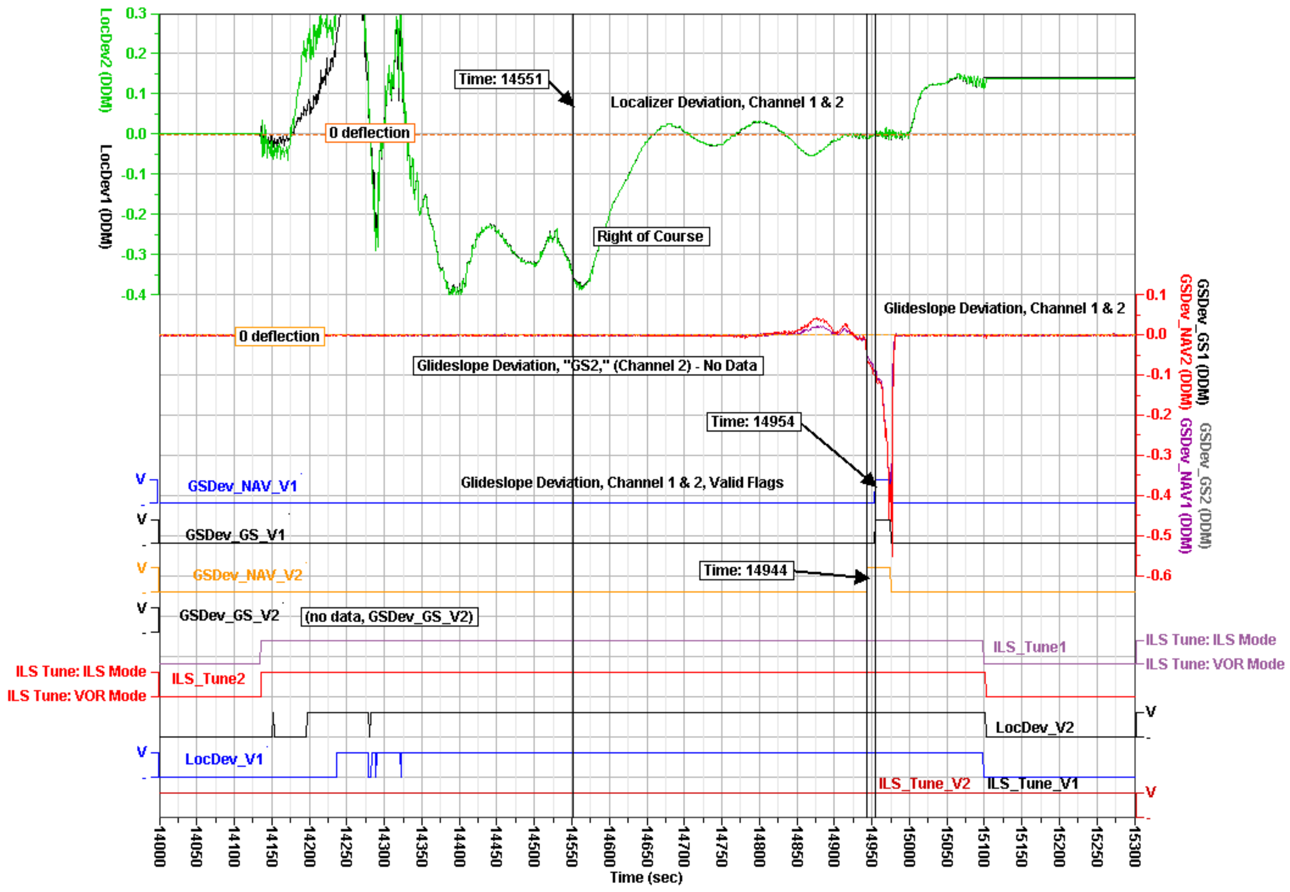


Figure 17. Log08, April 6, 2015 - localizer and glideslope deviations compared to Google Earth overlay.



Revised: 13 August 2015 Log08-4/6/15-IND Loc/GS Validation National Transportation Safety Board

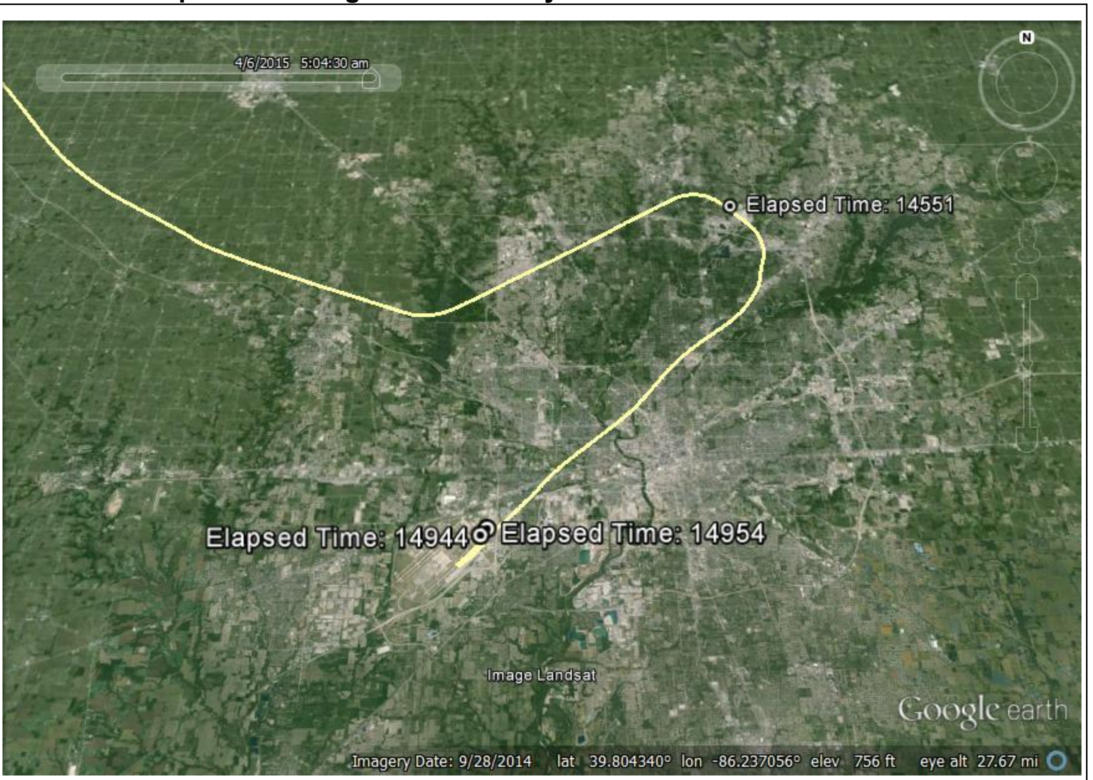
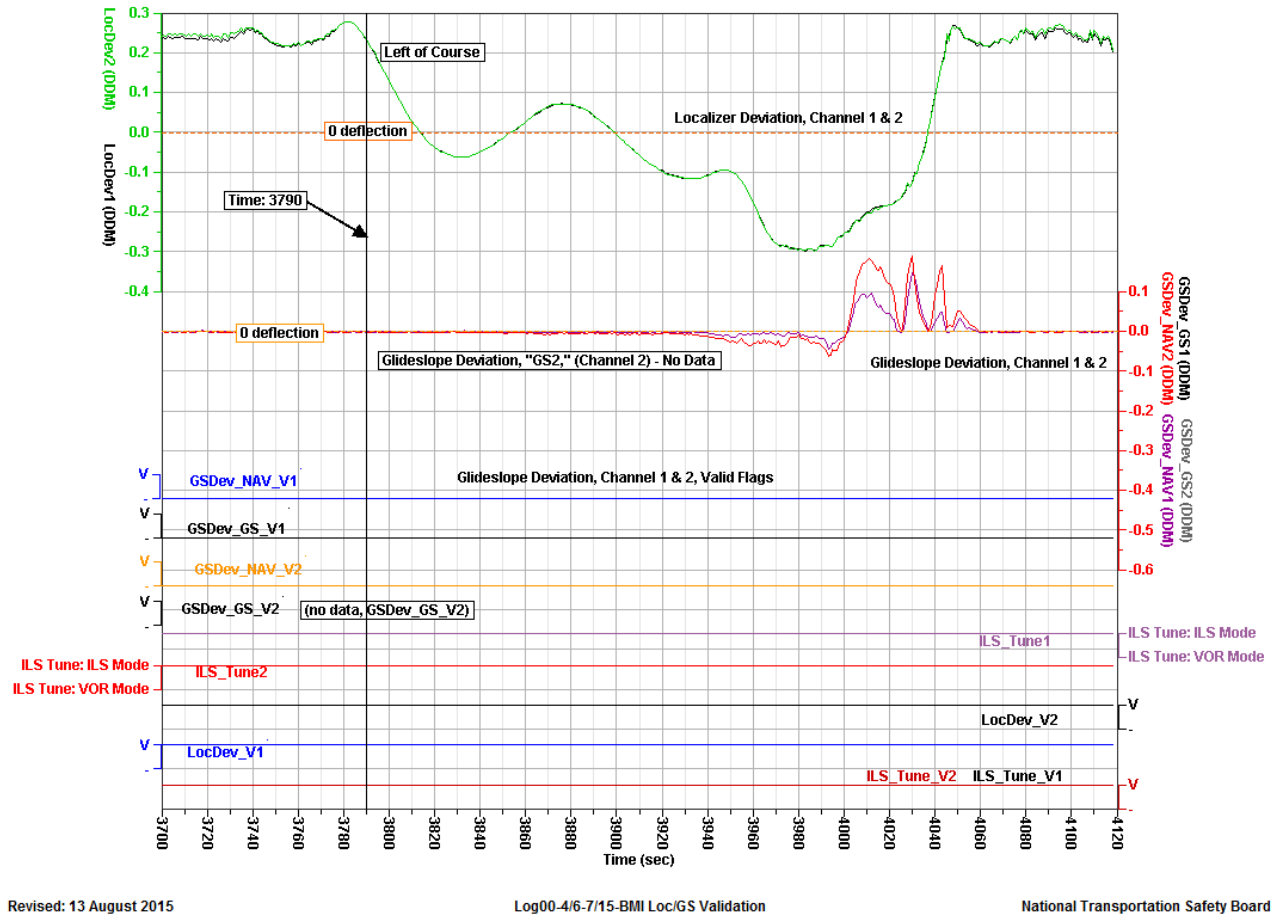


Figure 18. Log00, April 6/7, 2015 - localizer and glideslope deviations compared to Google Earth overlay (accident flight).



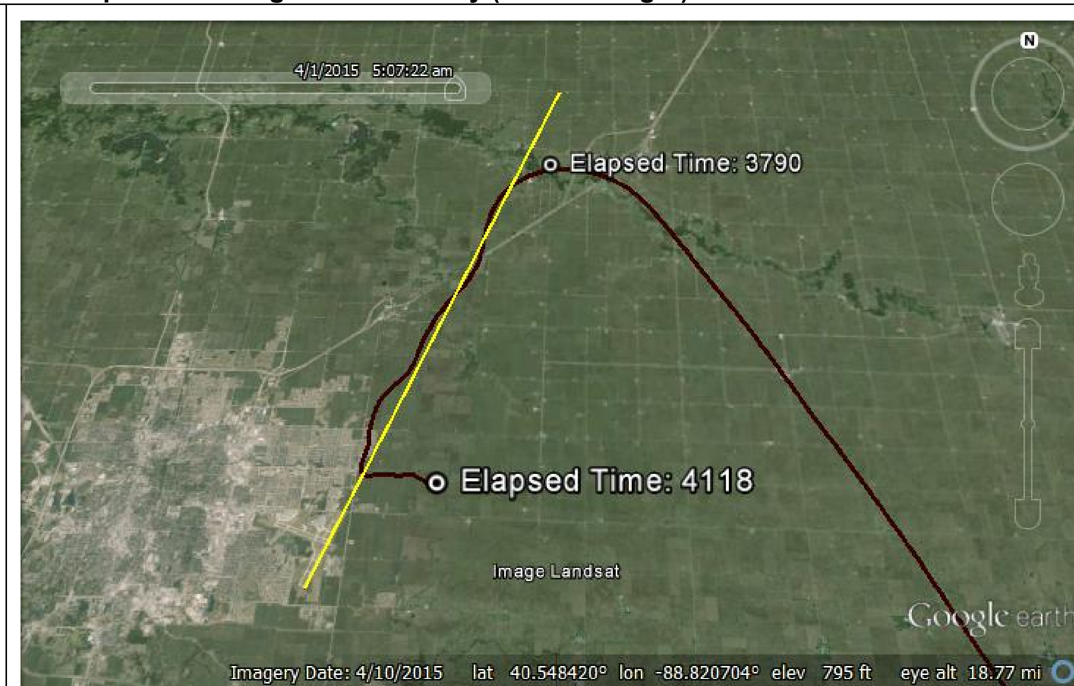


Figure 19. Accident flight path overlaid on the FAA BMI ILS Runway 20 approach chart (planview).

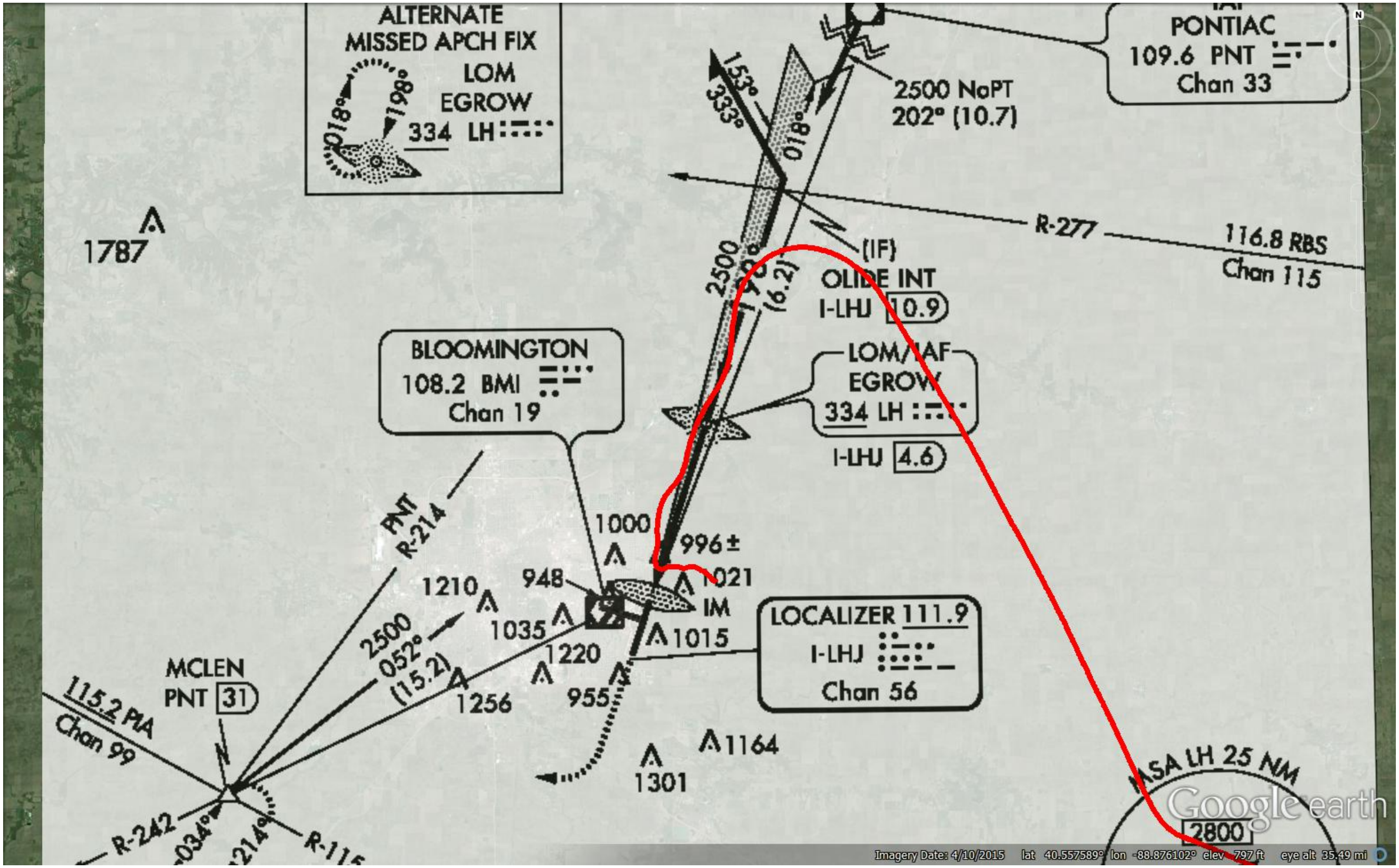


Figure 20. Accident flight parameters.

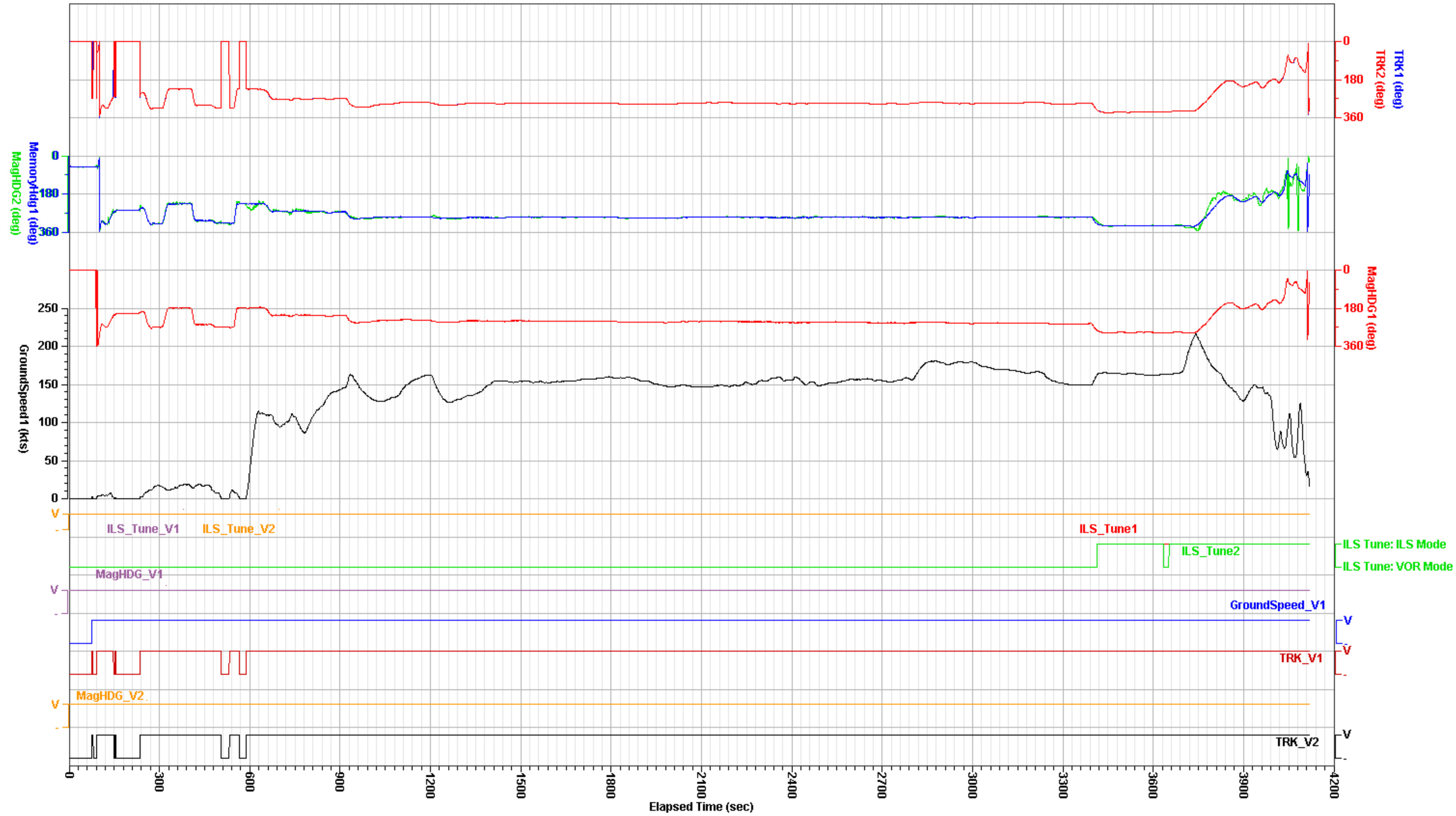


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Figure 21. End of accident flight parameters.