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

March 8, 2016

Sandel SN3500 Study Report

By Bill Tuccio, Ph.D.

1. EVENT SUMMARY

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. GROUP

A group was convened.

Chairman:	Dr. Bill Tuccio Aerospace Engineer National Transportation Safety Board (NTSB)
Member:	Ken Kochi Project Manager Sandel Avionics, Inc.
Member:	Mark Krause Senior Software Engineer Sandel Avionics, Inc.

3. Purpose of Study

The purpose of this study was to: (1) functionally test the Sandel SN3500 Navigation Indicator installed on the accident aircraft (unit serial number 1058), and (2) replay data recorded by the Sandel SN3500 on the same Sandel SN3500 to document navigational displays.[1] Lab work supporting this investigation was conducted at the facilities of Sandel Avionics, Inc. on December 21, 2015 by the group members identified in this report.

3.1. Background

The Sandel SN3500 is an electronic navigation indicator, similar in functionality to an analog horizontal situation indicator. Sandel designed the SN3500 to have a limited recording capability to a 24 megabyte (MB), non-volatile memory,[2] circular buffer for diagnostic purposes (as described in the factual report[1]). The recording logic is such that, for each power cycle, the oldest 12 MB of data is erased from the circular buffer to make room for new data. This erasure can be inhibited through a special startup sequence to "factory mode."

In addition to the circular buffer, configuration and setting data are stored to non-volatile memory every time a change is made, overwriting prior configuration and settings (in other words, only the last configuration and settings are stored with no time history).

The circular buffer is binary data, with each data element consisting of eight hexadecimal characters (a 32-bit word). Each binary word is a coded representation of an associated ARINC 429 data element.[3] During product design, Sandel decided which data elements to write to the circular buffer for diagnostic purposes; as such, not all data available to the SN3500 in real time is written to the circular buffer (for example, the marker beacon displays, heading bug, course selection, map range, etc.).

When recorded, circular buffer data is sampled once per second (1 Hz). Each sample records all targeted ARINC 429 data elements for channels "1" and "2." The two channel definition generally coincides with two navigational inputs. Channel 1 typically receives the first GPS and the first radio navigation aids, and Channel 2 typically receives the second GPS and the second radio navigation aids. For the accident aircraft configuration, Channel 1 corresponded to a Garmin 530, and Channel 2 corresponded to a Garmin 430.

The binary data is converted to human-readable ARINC 429 coded text via a proprietary program developed by Sandel. The human-readable ARINC 429 coded text was used to produce the aforementioned factual report.[1] Sandel has proprietary software and

[1] For a factual description of installed avionics, including the Sandel SN3500, see the Specialist's Factual Report of Multiple Electronic Devices in the public docket for this accident.

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

[3] ARINC (Aeronautical Radio, Inc.) is a corporation with stakeholders from aviation and one of its activities is the creation of standards. ARINC 429 is a standard for the exchange of digital data between avionics systems.

hardware to send the captured ARINC 429 data back to the Sandel unit to drive the navigational display, thus replaying (with some limitations) what was displayed when the data was recorded. One limitation of the replay framework was only the Channel 1 navigation data was able to be sent to the SN3500 unit (due to a failed ARINC 429 transmission port in the test stand). Sandel also has the ability to replay the captured ARINC 429 data to a PC-based emulation of the Sandel unit; this PC-based emulation supports both Channel 1 and Channel 2.

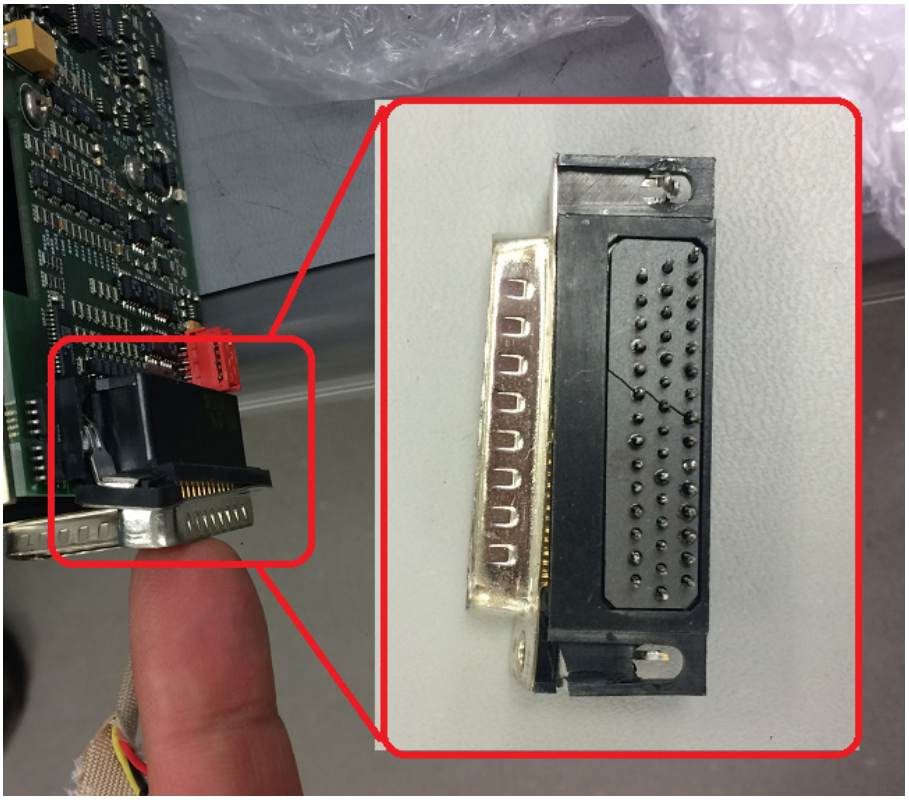
Configuration and setting data is also stored as binary data. A proprietary Sandel program reads the configuration data, token by token,[4] and converts each data token to human readable format. When the configuration and setting data is reloaded to the SN3500, the human readable format is converted to binary data and then written to the SN3500.

Sandel has the ability to run an input/output test ("factory i/o test"). In the factory i/o test, a matrix of configuration and settings are run against a matrix of known inputs with expected outputs. The configuration and settings are compared to the known inputs and outputs, producing a matrix of pass/fail conditions. By its nature, the factory i/o test overwrites the firmware, configuration, and settings on the unit; however, by running the factory i/o test in factory mode, the circular buffer recording history may be preserved. Also during the factory i/o test, the flux gate compass is recalibrated to the test environment.

Two items were not working on the accident unit: the cooling fan and the P2 serial connector. The cooling fan was not repaired; rather, an external fan was setup next to the unit while it was running the tests. The P2 serial connector, shown in figure 1, was removed and a new P2 serial connector was soldered in place.

[4] In this context, tokens are codes that represent data. For example, MODE1 may refer to a display mode.

Figure 1. Damaged P2 connector (inset shows close-up of damage after removal).



3.2. Methodology

Considering the background information in Section 3.1, the following methodology was used to achieve the purposes of this study.

1. Download and store the circular buffer from the accident unit as binary data.
2. Download and store the configuration and settings as binary data.
3. Convert the binary data to ARINC 429 words using the Sandel proprietary program.
4. In factory mode, feed the ARINC 429 data for each flight recording to the Sandel SN3500 accident unit, using Sandel proprietary software and hardware for Channel 1. Capture the replay with a digital recorder.
5. In factory mode, run the factory i/o test (including updating the configurations, settings, and firmware). Document the results.
6. Feed the ARINC 429 data for the accident flight recording to the Sandel PC-based SN3500 emulator, using Sandel proprietary software and hardware for Channel 1; thereafter, feed the ARINC 429 data for each Channel 2 flight recording to the Sandel PC-based SN3500 emulation, using Sandel proprietary software and hardware. Capture the replay with a digital recorder.
7. Reset the firmware, configuration, and settings of the accident unit to the accident state.

3.3. Delimitations

The functionality test of the accident unit was limited to the factory i/o test. Other tests, such as display colors, input knobs and buttons were not tested. During the factory i/o test, the firmware was changed to a diagnostic version of the production firmware, which may affect the results (i.e., by causing behavior that was not identical to unit behavior at the time of the accident).

The replay of recorded data was subject to the following delimitations:

- **Interpolation.** Recorded data was only recorded at 1 Hz; however, the replay framework interpolated values to a sample rate of 10 Hz to smooth the replay presentation.
- **Time.** Hardware replay did not display time; as such, alignment to recorded data would have to be done by aligning discrete events. PC-based emulator replay displayed recorded UTC time in a small window beneath the playback.
- **Incomplete Data.** As mentioned in Section 3.1, only a subset of real time data used by the SN3500 was recorded to memory; therefore, the replay may present screens that are only an approximation of what was observed by the pilot on the flights documented in this report.
- **Binary Data Conversions.** Binary data downloaded from the circular buffer was converted to ARINC 429 data by software, and then retransmitted to the Sandel SN3500 and the PC-based emulator. The conversion and transmittal process may have introduced errors (i.e., if the PC-based emulator had errors in the coding).
- **Magnetic Heading.** The Sandel SN3500 supports various interfaces for magnetic heading. The accident unit was configured to receive two elemental inputs supporting magnetic heading: (a) gyro values from a Mid Continent gyro and (b) flux gate values from an S-TEC 6446 flux gate (see configuration screen shown in figure 2). The Sandel SN3500 combined these values in real time to produce the displayed magnetic heading. Values from the Mid Continent gyro, S-TEC flux gate, and resulting displayed heading were recorded at 1 Hz.

  The replay framework was not capable of sending the gyro and flux gate values to the Sandel unit for re-composition to displayed magnetic heading. Therefore, the accident unit gyro configuration was changed to receive an ARINC 429 magnetic heading, as shown in figure 3. The replay framework then sent the recorded, originally displayed magnetic heading to the unit, as if the source was ARINC 429 heading from an external source.

Figure 2. Accident unit original gyro configuration screen.

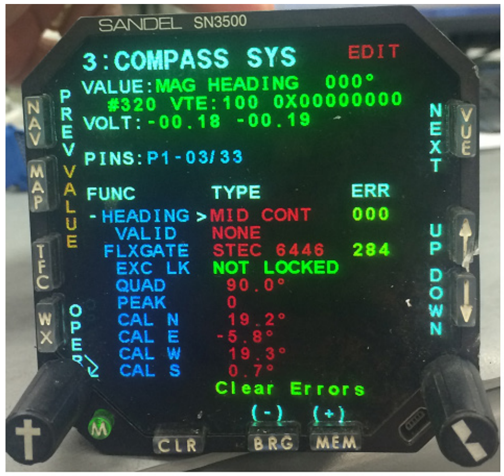
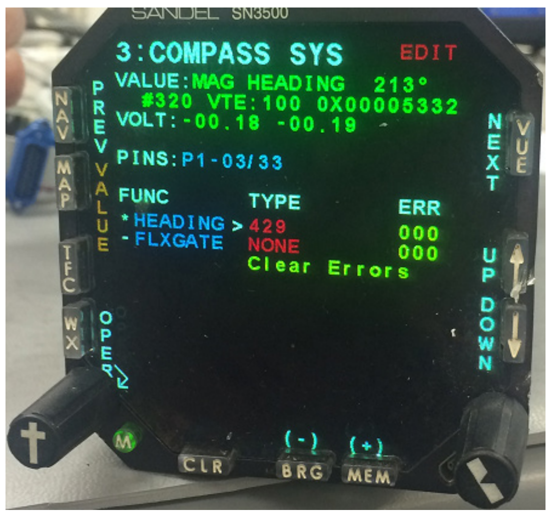


Figure 3. Accident unit with updated gyro configuration for replay.



3.4. Results

3.4.1. Sampling of Screen Displays

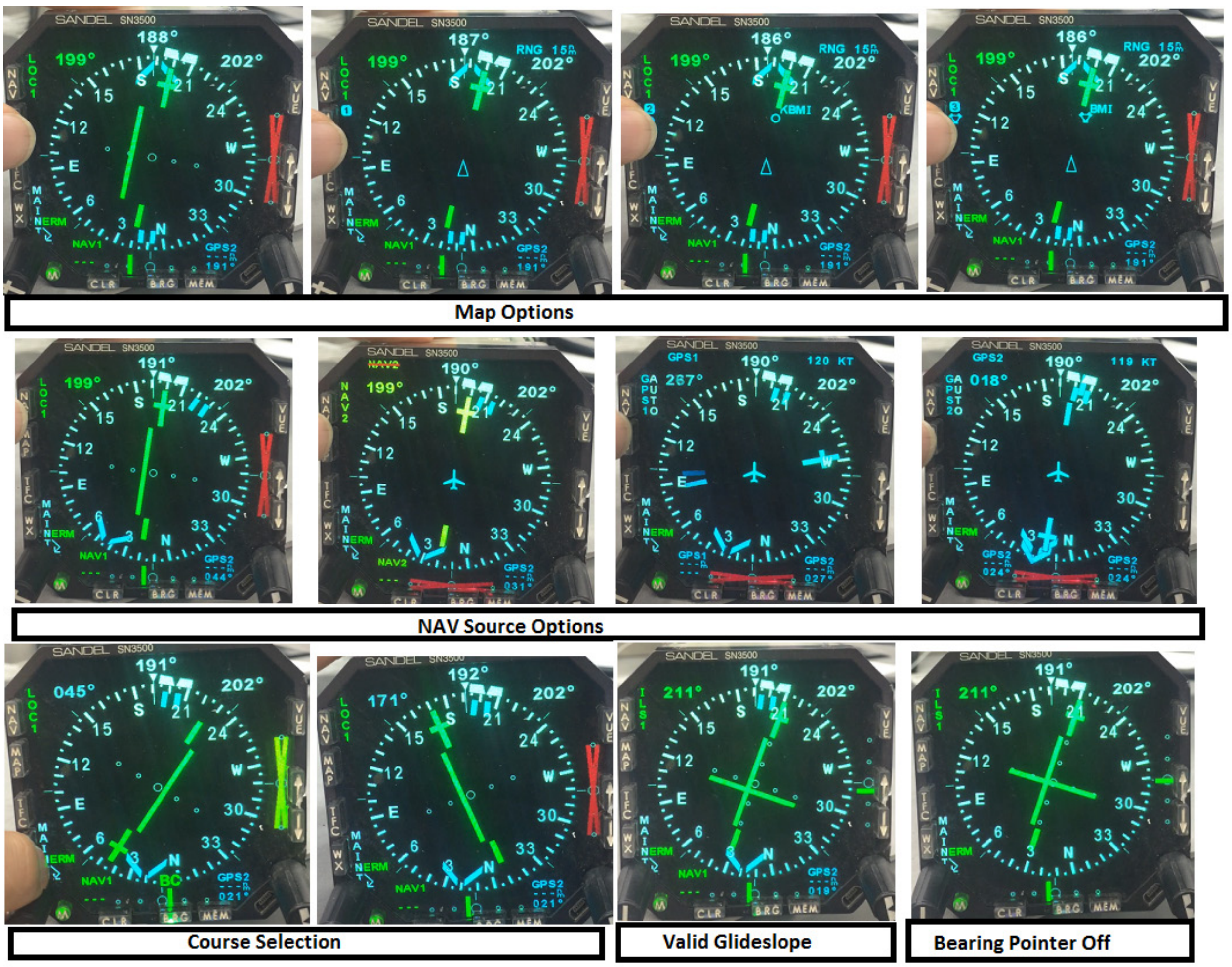
Before beginning the replay of recorded data, possible screen displays presented to the pilot were explored. Figure 4 shows a sample of select screen displays. The top row shows possible map options which may be selected. The second row shows various navigation source selections; from left to right: Nav 1, Nav 2, GPS 1, and GPS 2.

The first two images of the third row show the course selection for the localizer. In the examples, the localizer course was likely the ILS 20 at BMI. The images show the course selected to 045 degrees and 171 degrees. Because the selected course was not recorded, the replay had to assume what course to select during the replay.

The third row shows how a valid glideslope signal is presented on the SN3500. The last image in the third row shows the bearing pointer turned off.

Other possible display options not shown in figure 4 include: arc view vs. compass rose view, zoom settings on the map, and variation of the heading bug.

Figure 4. Sample of screen configurations.



3.4.2. Replays

Replays were conducted for the approach phase of each flight. The starting point was generally selected before a discrete event, such as the localizer becoming valid. Table 1 summarizes the replays and the attachments to this report containing the replay video. All Channel 1 recordings were replayed on the accident Sandel unit. All Channel 2 recordings were played back on a PC-based SN3500 emulator. For the accident flight (log_00), Channel 1 was also replayed on the PC-based SN3500 emulator.

Table 1. Replay attachments.

Log File	Log_00	Log_01	Log_04	Log_06	Log_08
Date	4/6-7, 2015	4/1/2015	4/2/2015	4/3/2015	4/6/2015
Description	BMI RWY 20	BMI RWY 20	MDW RWY 31R	BMI RWY 29	IND RWY 23R
	Attachment Number				
Channel 1	1, 2	4	6	8	10
Channel 2	3	5	7	9	11

The later part of attachment 5 shows the affect arc view and range changes have on the display. As stated previously, it was not possible to determine what range or compass rose view was selected by the pilot.

3.4.3. Functional Test

The functional test consisted of the factory i/o test. All tests passed with the exception of the gyro input. As discussed in Section 3.3, the magnetic heading displayed on the Sandel unit has two component inputs: a gyro value and a flux gate value. The gyro component provided no response during the factory i/o test and therefore failed.

During one step of the factory i/o test, power was applied to the accident unit without the unit being in factory mode. The non-factory mode power application likely caused erasure of part of the oldest recording (log_01) from the accident unit.

3.5. Discussion

3.5.1. Replays

During the accident flight, the glideslope never became valid on Channel 1 or 2. On other flights, the glideslope was valid, but later than would be expected.[5] Figure 5 shows select frames from the accident replay (log_00) for Channel 1, replayed on the accident unit. Times used in figure 5 correspond to elapsed times of the video recording of the playback from attachment 1. When red arrows are used to annotate a heading change, the red arrows show the direction of movement of the compass card.

At 00:11 (near the beginning of the replay recording), the aircraft was on a 291° heading, with navigation radio 1 tuned and receiving a VOR.

At 00:24, the aircraft began a right turn towards 330° (the red arrow annotates the counterclockwise direction of movement of the compass card).

At 00:41, while in the turn to 330°, navigation radio 1 tuned to a localizer frequency that was flagged invalid for the localizer and glideslope. The glideslope invalid “X” was yellow[6].

[5] For example, the expected behavior of the glideslope would be for a valid signal before passing the outer marker.
[6] See Section 4, “Limitations,” for an explanation of limitations of color fidelity.

At 00:49, KBMI first appeared on the SN3500 moving map. Due to the limitations of the replay discussed in Section 3.3, it is not known if the map was displayed on the accident flight and, if it was, what range was set to display.

At 03:04, while still on a 330° heading, the localizer first became valid. The localizer scale displayed a "BC" annunciation, indicating a back course condition. The BC annunciation is expected behavior of the SN3500 when the aircraft heading is more than 90 degrees offset from the selected inbound course. The localizer needle was full scale to the right.

At 04:52, the localizer needle moved from full scale right to full scale left.

By 07:18, the aircraft was in a left turn towards about 200°. As the aircraft passed through 289°, the BC annunciation extinguished and the localizer needle moved from full scale left to full scale right. The glideslope invalid "X" changed from yellow to red and remained red until aircraft heading changed significantly later in the approach (the change to a yellow "X" was accompanied by the "BC" annunciation[7]).

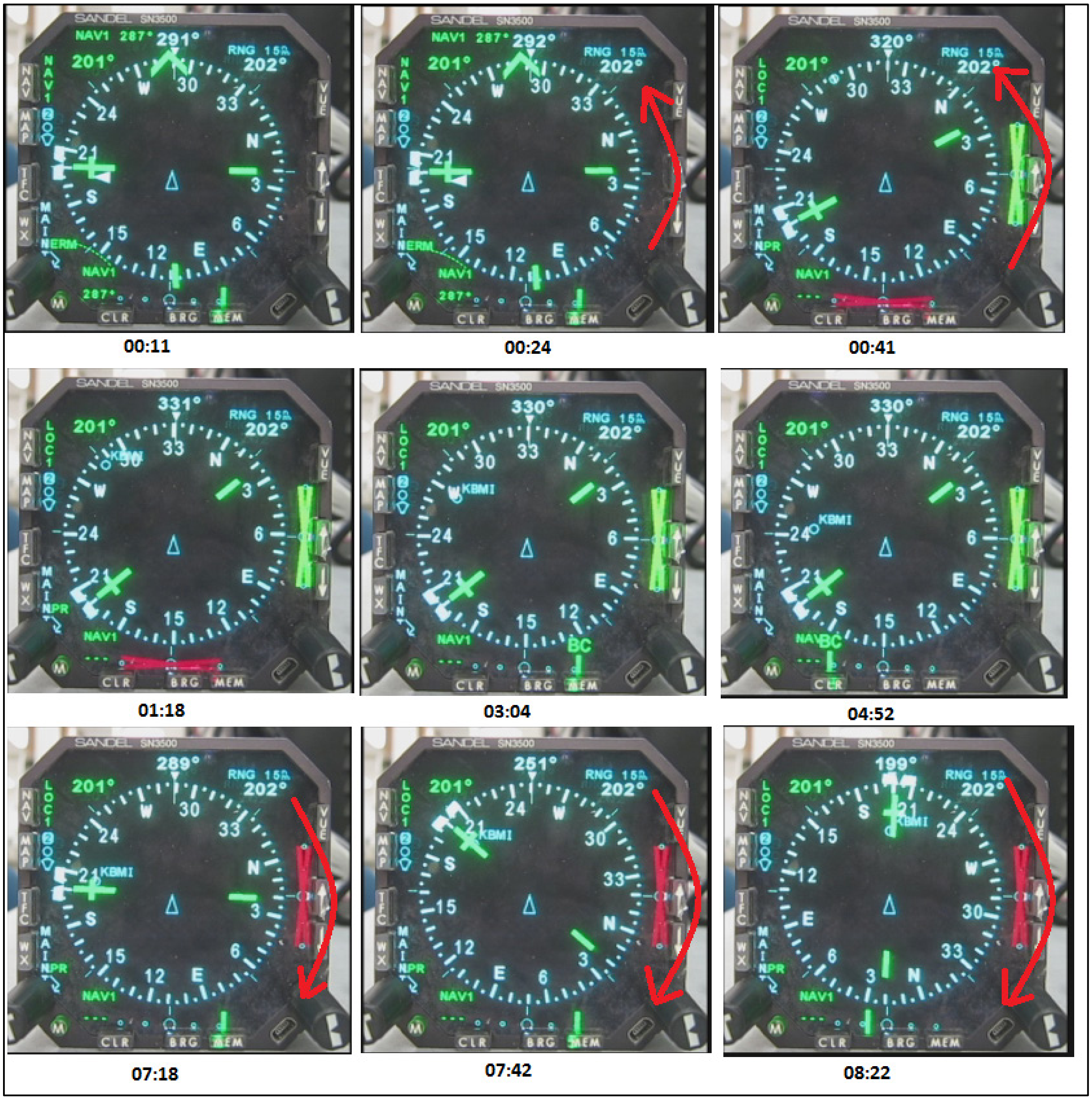
At 07:42, while still in the left turn, the localizer needle was no longer full scale and began to move towards the left.

At 08:22, the rate of left turn slowed and the localizer needle (which had passed through center and was displaced to the left) began to move right.

Throughout the recording, the glideslope needle always displayed an "X," indicating it was never valid. After 04:52, the localizer needle remained valid until the end of the recording. By about 10:39, the localizer needle was full scale left. Thereafter, heading and localizer fluctuated until the end of the recording.

[7] According to the Sandel SN3500 Pilot's Guide, "Large yellow 'X' through glideslope scale (VDI) to show that you are on backcourse approach."

Figure 5. Select frames from accident flight (log_00, channel 1)



3.5.2. Functional Test

The only failed i/o test was the gyro component. Recorded gyro, flux gate, resulting magnetic heading, and track data were examined in the recorded data. The recorded values appeared to be correct. Further, it was observed if the gyro was failed on the accident flight in the same manner it had failed during the i/o test, the gyro would have produced a constant value. Therefore, it is likely the gyro failed the i/o test as a result of damaged sustained during the accident sequence.

Damage was also observed to the right knob of the SN3500. The damage inhibited full rotation of the knob and was consistent with impact damage from the accident.

4. Limitations

In addition to the delimitations of the study, interpretation of the results are limited to include:

- **Other Displays.** The accident aircraft ostensibly had other indicators connected to the Garmin 530/430 output, including analog course deviation indicators and indirectly via the flight director. This study did not address what was shown on other displays.
- **Garmin 530/430 NAV/GPS Selection Interface.** The means by which the pilot selects GPS or NAV (localizer or VOR navigation) is installation specific. Options include (but not limited to) an external switch or an integration with the SN3500 NAV/GPS selection. This study did not address these selection options.
- **TERM, APPR Mode Annunciations.** During playback, validity of annunciations of TERM and APPR mode were not assessed. As such, these indications should not be used to reach any conclusions.
- **Factory I/O Test Gyro Component Failure.** When the factory i/o test determined the gyro failed, in agreement with the IIC it was decided not to attempt to identify the failure through further hardware testing. Attribution of the gyro failure to impact damage was done inferentially by examination of recorded log data. This attribution was made with a high degree of confidence.
- **Hardware Display Colors.** The fidelity of the colors shown on the accident unit were limited and green sometime looked like yellow. The cause of this color distortion was not determined (e.g., accident damage versus pre-existing condition).

5. Conclusion

The Sandel SN3500 was damaged in the accident, but all basic functions were likely operative during the accident flight. The glideslope from Channel 1 and 2 were never valid on the accident flight and the Sandel SN3500 reported the invalid condition on the Sandel SN3500 display.