NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

February 19, 2003

Addendum to Systems Group Chairman's Factual Report
DCA02MA054

A. ACCIDENT

Location:	Tallahassee, Florida
Date:	July 26, 2002
Time:	0537 Eastern daylight time (EDT)
Aircraft:	FedEx Flight 1478, a Boeing 727-232, N497FE

B. SYSTEMS GROUP

Chairman:	Tom Jacky National Transportation Safety Board Washington, DC
Member:	Bob Brown Air Line Pilots Association (ALPA) Memphis, TN
Member:	Frank Matthews Boeing Commercial Airplane Group Seattle, WA
Member:	Scott Foster FedEx Express Memphis, TN

C. SUMMARY

On July 26, 2002, at 0537 eastern daylight time, a FedEx B-727, N497FE, crashed on final approach to Tallahassee Regional Airport, Florida. The airplane was operating as Flight 1478 from Memphis, Tennessee, to Tallahassee. The airplane crashed short of runway 9, and was subsequently destroyed by impact and post-crash fire.

The airplane's ground proximity warning system (GPWS) computer's performance was examined for the accident approach. Using information from the airplane's flight data recorder (FDR), cockpit voice recorder (CVR), and recorded

radar data, calculations were applied to flight data and the results were plotted to allow comparisons with each of the GPWS seven alert modes.

The results of the examination confirm the GPWS correctly issued a Mode 6 bank angle alert. The bank angle aural annunciation "BANK ANGLE BANK ANGLE" was noted on the CVR transcript at 537:22.6 EDT, and the flight data calculations confirm the Mode 6 bank angle alert envelope was penetrated at that time. According to the calculations performed in this study, no additional GPWS alert thresholds were crossed. Each of the GPWS Mode 6 altitude callouts noted on the CVR transcript were annunciated to the flight crew within 1 second of when the FDR data indicates the airplane passed through the altitude.

The calculations used for this effort were not intended to exactly replicate the methodology of the GPWS computer. The calculations were intended to provide an estimate of the airplane's proximity to the various GPWS mode envelopes.

D. DETAILS OF INVESTIGATION

1. Description of Ground Proximity Warning System (GPWS)

The Ground Proximity Warning System (GPWS) automatically warns the flight crew of a potentially dangerous flight path relative to the ground beneath the airplane. The GPWS will provide a visual and aural alert to the flight crew whenever one of the following thresholds is exceeded between 50 and 2,450 feet radio altitude:

Mode 1 – Excessive Descent Rate with a "Sink Rate" aural warning;

Mode 2 – Excessive Terrain Closure Rate with a "Terrain" aural warning;

Mode 3 – Altitude Loss After Takeoff or Go-around with a "Don't Sink" aural warning;

Mode 4 – Unsafe Terrain Clearance During high speed flight or while not in the landing configuration with a "Too Low Gear" aural warning;

Mode 5 - Below Glideslope Deviation Alert with a "Glideslope" aural warning;

Mode 6 – Bank angle and altitude callouts;

Mode 7 – Windshear determination with "Windshear" aural warning.

The GPWS will not issue a warning for landing short of the runway if the airplane is in landing configuration and descending at a normal rate or flying directly towards a sheer cliff with no preceding rising terrain.

The GPWS computer receives inputs from the following:

-Captain or number 1 radio altimeter,

-Number 1 air data computer system (altitude rate and mach/airspeed),

-Number 1 navigation receiver glideslope signals,

-Landing gear and flap positions.

The loss of one of these inputs will deactivate only the affected mode or modes.

A Sundstrand Data Corporation ground proximity-warning computer (GPWC), part number 965-0876-001-B05-B01, serial number unknown, was recovered from the wreckage. The unit was crushed and damaged by fire. The airline indicated the GPWS computer is located in the electronics compartment (E & E bay) on the E5-4 shelf.

2. Description of Input Data and GPWS Alert Envelopes

A. Input Data From FDR, CVR and Recorded Radar Data

For this study, data were incorporated from the flight data recorder (FDR), cockpit voice recorder (CVR) and recorded radar data.

An electronic file of FDR data was received from the chairman of the FDR Group. The file included data from 6,575 to 7,200 seconds FDR Time. The file included data for the following FDR parameters:

a) FDR Time in Seconds
b) Pressure Altitude
c) Computed Airspeed
d) Roll
e) Radio Altitude
f) Flap Position (Left and Right Inboard, Left and Right Outboard)

Each of the listed FDR parameters were recorded at a rate of once per second (1 Hz). For additional information regarding the FDR data, please refer to Flight Data Recorder Group Chairman's Solid State Flight Data Recorder Factual.

The Group Chairman's Factual Report of Investigation Cockpit Voice Recorder was used to document the timing of the GPWS aural alerts and altitude callouts that were annunciated to the flight crew. These excerpts included:

Eastern Daylight Time (hhmm:ss)	GPWS Aural Annunciation
5:36:20.2	1,000 Feet
5:36:47.8	500 Feet
5:37:14.0	100 Feet
5:37:19.9	50 Feet
5:37:20.3	40 Feet
5:37:21.0	30 Feet
5:37:22.6	Bank Angle, Bank Angle

The recorded radar data was used to determine the distance from the Runway 9 threshold. The data were obtained from the Chairman of the Aircraft Performance Group, in a Microsoft Excel spreadsheet. The data were interpolated to 8 Hertz (Hz) for the time period from 7,072.02 to 7,196.39 seconds FDR Time. The spreadsheet included the following data:

a) FDR Time (Seconds from beginning of transcription);
b) Total Time in Seconds;
c) Coordinated Universal Time (UTC) Total Time of Day;
d) UTC in hours, minutes, and seconds;
e) FDR Radio Altitude;
f) Distance To Runway (Feet);
g) FDR Roll Angle (phi);
h) FDR Pressure Altitude (Feet);
i) FDR Computed Airspeed (Knots);
j) True Airspeed (feet/second).

B. GPWS Mode Alert Envelopes

The manufacturer of the GPWS computer, Honeywell, provided information regarding the operation of the GPWS and details regarding the alert envelopes for each mode. The information included a description of each mode and phase(s) of flight for which each mode was valid. For each mode, the boundaries of the mode were plotted as X-Y coordinates to allow for comparison with data from the FDR or with data derived from the FDR parameters.

3. Data Derived For GPWS Alert Envelope Comparison

For this exercise, the following data were calculated:

a) Pressure Altitude Vertical Speed (feet/minute);

b) Terrain Closure Rate (Radio altitude rate in feet/minute);
c) Absolute Value of Bank Angle;
d) Local Time (EDT);
e) Distance From Runway in nautical miles:

A spreadsheet of FDR data, data provided by the Aircraft Performance Group Chairman, and resultant, calculated data, is included in Attachment 1. The name of each column of data, its origination and/or how calculated is as follows:

a) FDR Time

Defined as seconds from beginning of FDR transcription.

b) Total Seconds:

FDR Time converted to Coordinated Universal Time (UTC), expressed in number of seconds from midnight. Refer to Cockpit Voice Recorder Timing And Correlation Study and Aircraft Performance Study for details on correlation of FDR time to UTC.

c) Coordinated Universal Time (UTC)

FDR Time converted to UTC, expressed in hours, minutes and seconds.

d) Radio Altitude

FDR parameter recorded at 1 Hertz, interpolated for this exercise to 8 Hz. Expressed in units of feet above ground level (AGL).

e) Distance To Runway

Expressed in feet from runway threshold. Data received from Aircraft Performance Group Chairman, please see Aircraft Performance Study for additional details on derivation of this data.

f) FDR Roll Angle

FDR parameter recorded at 1 Hertz, interpolated for this exercise to 8 Hz. Expressed in degrees.

g) FDR Pressure Altitude

FDR parameter recorded at 1 Hertz, interpolated for this exercise to 8 Hz. Expressed in feet.

h) Vertical Speed

Calculated as a rate of pressure altitude change and expressed in units of feet per minute. The data were calculated on a point-to-point basis and were not smoothed or averaged.

i) Terrain Clearance Rate

Calculated as rate of change of radio altitude data and expressed in units of feet per minute. The data were not smoothed or averaged.

j) Absolute Value of Roll

The absolute values of each FDR roll data point. Expressed in degrees.

k) Eastern Daylight Time

Coordinated Universal Time converted to EDT by subtracting 4 hours. Expressed in hours, minutes, and seconds from midnight.

l) Computed Airspeed

FDR parameter recorded at 1 Hertz, interpolated for this exercise to 8 Hz. Expressed in knots.

m) Distance to Runway

See e) above, converted to nautical miles from runway threshold.

4. Comparison of FedEx 1478 Flight Data to GPWS Alert Envelopes

For each mode, the pertinent FedEx 1478 data or results of the calculations were formatted to the GPWS mode envelope. The boundaries of each mode were also plotted for comparison to the FedEx 1478 data. Each plot was then examined for determination as to whether the GPWS mode boundary was penetrated by the flight data. For each alert plot, a warning is generated when the flight data penetrates the mode boundary, generally from "left to right" across the plot.

A discussion of each GPWS alert mode and results follows.

A) Mode 1 – Excessive Descent Rate

For Mode 1, an alert is provided when the airplane has an excessive descent rate close to terrain. Barometric pressure altitude rate, a calculated parameter, was plotted versus radio altitude for radio altitude values

approximately 2,000 feet AGL and lower. The resultant data provided no indication of calculated warnings. A plot of the data is included in Attachment 2.

B) Mode 2 – Excessive Terrain Closure Rate

This mode consists of two sub-modes: Mode 2a (for airplane in non-landing configuration) and 2b (for airplane in landing configuration). For Mode 2, the GPWS compares Terrain Closure Rate (TCR) versus Radio Altitude.

FedEx indicated that, for this airplane, landing configuration is landing gear down and flap extension greater than 27.5°. The CVR transcript indicates the landing gear was extended at 535:33.6 EDT, and, based on the FDR data, flaps were extended beyond 27.5° at 536:46.38 EDT. Therefore, the airplane was considered to transition from Mode 2A to 2B at 536:46.38 EDT, when the airplane first had extended landing gear and flaps beyond 27.5°.

TCR, calculated as a rate of radio altitude change, was plotted versus radio altitude. The Mode 2A plot, plot 3-1, and Mode 2B plot, plot 3-2, are included in Attachment 3. In addition, the flight data does not differentiate from landing and non-landing configuration. Examination of the resultant plots indicates no calculated penetration of the Mode 2A or 2B envelopes.

C) Mode 3 – Sink After Takeoff

Mode 3 is active during the takeoff and missed approach phase of flight. Since FedEx flight 1478 was on approach, Mode 3 was ignored.

D) Mode 4 – Unsafe Terrain Clearance

This mode consists of three sub-modes: Mode 4A (cruise and approach, gear not down) 4B (cruise and approach, gear down), and 4C (takeoff phase). For this study, only Mode 4B was examined. The time examined was between gear extension (per CVR at 535:33.6 EDT) and prior to extension of flaps into landing position (according to FedEx, flaps extended beyond 27.5 degrees, at 7,162.34 FDR Time). Data for computed airspeed were plotted versus radio altitude during this time period. Examination of the resultant plots indicates no penetration of the Mode 4B envelope. The plot is included in Attachment 4.

E) Mode 5 – Excessive Glideslope Deviation

Mode 5 is active during approach when the GPWS computer detects a glideslope signal. Since the airplane was flying an approach without an instrument landing system (ILS), this mode was ignored.

F) Mode 6 – Excessive Bank Angle

FDR data were used for this mode, rather than the interpolated data. The absolute value of FDR roll angle was plotted versus terrain clearance (radio altitude). The resultant plot is included in Attachment 5.

The data indicates a penetration of the bank angle envelope boundary at 7,197.81 seconds FDR time. The CVR transcript indicates an aural "bank angle" at 537:22.6 EDT, which converts to FDR time 7,198.56 seconds. Therefore, the GPWS "bank angle, bank angle" warning was annunciated 0.75 seconds after penetration of the bank angle boundary.

G) Mode 6 – Altitude Call-Outs

The GPWS altitude callouts in the CVR transcript were compared against the FDR radio altitude data. The CVR transcript time of the callout was converted to FDR time. The converted time was then compared to the FDR time of the first radio altitude value less than the callout value (e.g. for 1,000 foot callout, a radio altitude of 998.24 at 7135.77 FDR Time). In each case, the FDR-recorded descent below the GPWS callout was within 1 second of the aural envelope penetration. The GPWS 30, 20, and 10 foot callouts were not compared, since no radio altitude values of less than 30 feet were recorded prior to the end of the data.

A spreadsheet comparison of the CVR times versus FDR times is included in Attachment 6. A plot of the data is also included in Attachment 6.

5. Enhanced GPWS Terrain Clearance Floor Comparison

FedEx indicated that the accident airplane was scheduled to have the GPWS computer replaced with a Honeywell Enhanced Ground Proximity Warning System (EGPWS). An effort was taken to determine what, if any, additional warnings an installed EGPWS would have provided the flight crew, given the airplane's flightpath.

A) Description of EGPWS

EGPWS uses Global Positioning System (GPS) precision position, aircraft altitude, and worldwide terrain/obstacle and runway databases to predict potential conflicts between airplane flight path and man-made obstacles and/or terrain. As a result of the databases, the EGPWS is able to provide terrain/obstacle alerting for enroute operation or when in vicinity of an airport.

One of the EGPWS alerts is the Terrain Clearance Floor (TCF) alert. The TCF alert is provided for all runways greater than 3,500 feet long. It creates an increasing terrain clearance envelope around the intended airport runway directly related to the distance from the runway. TCF alerts are based on current aircraft location, nearest runway location, and radio altitude. TCF is active during

takeoff, cruise and final approach. This alert complements existing Mode 4 protection by providing an alert based on insufficient terrain clearance even when in full landing configuration on a non-precision approach. Alerts for TCF illuminate EGPWS cockpit lamps and produce aural messages. When an aircraft penetrates the TCF alert envelope the aural message "TOO LOW TERRAIN" will be given. No video alert is provided with the TCF alerts.

B. Comparison of FedEx 1478 Data With EGPWS

Honeywell provided documentation of the TCF envelope. The FedEx 1478 flight data, converted to distance from runway threshold, was plotted versus radio altitude. The resultant plot is included in Attachment 7.

Examination of the data suggests that FedEx 1478's flightpath would not have generated an EGPWS TCF alarm.

Honeywell also provided information regarding a proposed change to the TCF envelope. The proposed change adds an "elbow" to the warning envelope at 1.25 nautical miles and 150 feet AGL. In addition, the edge of the warning envelope was moved from 0.5 nautical miles to 0.25 nautical miles from runway threshold.

Using the proposed TCF envelope, the FedEx 1478 flightpath would have generated warnings at the following times:

1. 537:04.3 EDT, 1.35 nautical miles, 155 feet AGL
2. 537:10.2 EDT, 1.12 nautical miles, 123.9 feet AGL

The proposed TCF envelope change is included in the plot in Attachment 7.

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Attachments

1. FedEx Flight 1478 Flight History Data
2. Mode 1 – Excessive Descent Rate Plot
3. Mode 2 – Excessive Terrain Closure Rate Plots
4. Mode 4 – Unsafe Terrain Clearance Plot
5. Mode 6 – Excessive Bank Angle Plot
6. Mode 6 – Altitude Callouts Comparison Table and Plot
7. EGPWS Terrain Clearance Floor Plot