

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



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SYSTEMS

Group Chair's Factual Report

March 15, 2023

TABLE OF CONTENTS

A. INCIDENT	3
B. SYSTEMS GROUP	3
C. DETAILS OF THE INVESTIGATION	4
1.0 FLIGHT MANAGEMENT COMPUTER SYSTEM (FMCS) DESCRIPTION (COURTESY OF GE)	4
2.0 FLIGHT MANAGEMENT COMPUTER SYSTEM (FMCS) DOWNLOAD.....	5
2.1 Flight Management Computer (FMC) Data.....	6
2.2 FMC Fault Data Sheet File	6
2.3 FMC Built-in Test Equipment (BITE) Data File.....	6
3.0 FAULT REPRODUCTION IN LAB	7
4.0 FMC FAULT DISCUSSION	7
APPENDIX A FMC FAULT DATA SHEET FILE.....	9
APPENDIX B FMC 1 AND 2 TRACEBACK DATA.....	11

A. INCIDENT

Location: Pittsburgh, Pennsylvania
Date: June 21, 2022
Time: 0944 eastern daylight time (EDT)
Airplane: Boeing 737-9 MAX, UAL2627, N37513

B. SYSTEMS GROUP

Group Chair	Adam Huray National Transportation Safety Board Washington, D.C.
Group Member	John Flynn National Transportation Safety Board Washington, D.C.
Group Member	Todd Gentry Federal Aviation Administration Washington, D.C.
Group Member	Eric East The Boeing Company Seattle, Washington
Group Member	David Huhn General Electric (GE) Grand Rapids, MI
Group Member	Ryan Hurling United Airlines Chicago, IL

C. DETAILS OF THE INVESTIGATION

1.0 Flight Management Computer System (FMCS) Description (Courtesy of GE)

The GE Aviation Flight Management Computer System (FMCS) is a part of the Flight Management System for the Boeing 737 aircraft. The FMCS interfaces with the aircraft to support lateral, vertical, and time-based navigation guidance for optimized flight profiles. The FMCS is installed in a variety of configurations depending upon the 737 model. The event aircraft contained two Model 2907C1 Flight Management Computers (FMCs), GE P/N: 176200-01-01. A simplified block diagram is shown in Figure 1.

In a dual configuration, the FMCS includes two interconnected FMCs operating as two independent navigators. Based on the position of the FMC source select switch, one FMC is designated as the "primary" and the other as "secondary". With the source select switch set to the "normal" position, both Control Display Units (CDUs) display data provided by the primary (left) FMC. The left navigation display is driven by the left FMC and the right navigation display is driven by the right FMC. At power up, the FMCs synchronize themselves to the same initial position and any flight plan data loaded. Continuous monitoring is performed to maintain synchronous operation, dropping to single FMC operation if a disagreement cannot be resolved.

The FMC monitors interfaces with certain other 737 avionics systems as well as its own internal operational integrity. The FMC records different parameters related to this monitoring across multiple files within the FMC file system.

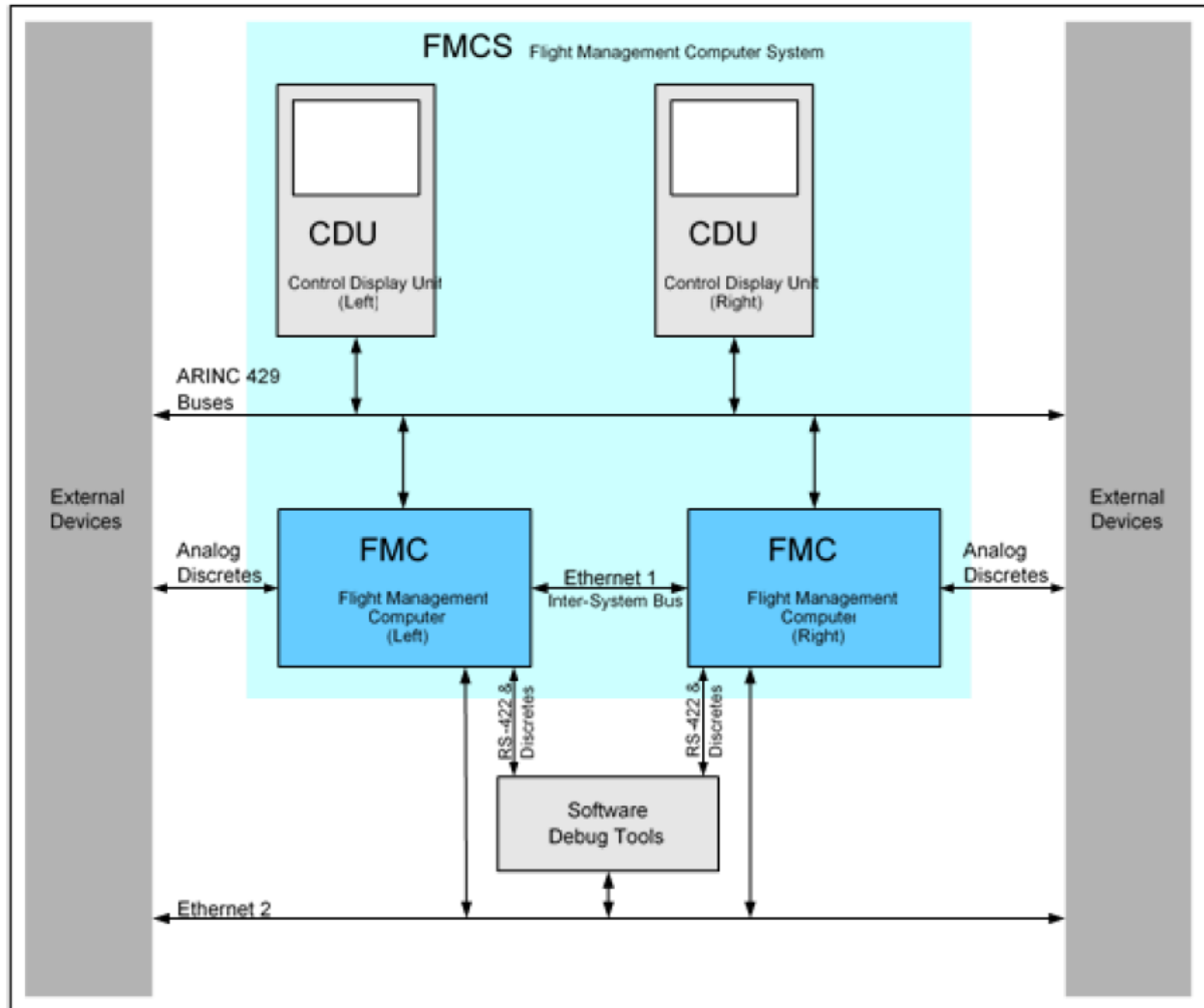


Figure 1. FMCS Simplified Block Diagram. (Courtesy of GE)

2.0 Flight Management Computer System (FMCS) Download

The following units were sent to GE Aviation (Grand Rapids) for investigation:

- FMC 1 (also referred to as Left FMC or FMC-L):
 - MFG Part Number (P/N): 176200-01-01
 - MFG Serial Number: 015170
 - Removed from Aircraft 7513 on 23 June 2022
- FMC 2 (also referred to as Right FMC or FMC-R):
 - MFG Part Number (P/N): 176200-01-01
 - MFG Serial Number: 015168
 - Removed from Aircraft 7513 on 4 July 2022

FMC 1 was downloaded immediately after the incident. FMC 2 was downloaded by GE on 19 July 2022.

2.1 Flight Management Computer (FMC) Data

Table 1 provides a summary of the configuration data associated with the incident aircraft's FMCs. The Operational Flight Program (OFP), Software (SW) options, and Model Engine Database (MEDB) are the same for both FMCs.

Table 1. FMC Information and Related Data.

L FMC Serial Number	015170
L Hardware Model	2907C1
R FMC Serial Number	015168
R Hardware Model	2907C1
OFP Part Number	650630-00-2 ¹
Nav Data Base ID	U737220601
SW Options ID	BCG-01T-R5
Model Engine dB ID	BCG-01T-A3

2.2 FMC Fault Data Sheet File

The fault data sheet file captured aircraft state information at the time a software exception occurred. Appendix A details these records for FMC 1 (S/N 015170) and FMC 2 (S/N 015168). Some data has been removed from the excerpt for conciseness. Only data pertinent for confirmation of the aircraft performance parameters and flight plan information was included in Appendix A.

As shown in Appendix A, both FMCs logged an exception during descent with a timestamp of "Jun 21, 2022 13:40:12". At the time of the software exception, Mode Control Panel (MCP) Altitude was 4000.0 ft, with Standard Terminal Arrival Route (STAR) ID "JESEY4", Flight Plan Waypoint "ROOSA (VECTOR) @@@@ NESTO ", and both FMCs set for Approach to Runway 28C into Pittsburgh International Airport (KPIT).

2.3 FMC Built-in Test Equipment (BITE) Data File

The FMC BITE Data File captures error code information for software exceptions experienced by the FMCs including traceback through the pertinent software modules in which the exception originated.

Appendix B details these records for FMC 1 and FMC 2. As shown in Appendix B, both FMCs logged a restart with error code "1A1" and a timestamp of "Jun 21, 2022 13:40:12".

¹ The OFP part number corresponds to the "U14" version of GE's 737 FMCS software.

3.0 FAULT REPRODUCTION IN LAB

The FMC reset from the event flight was able to be reproduced in a lab environment using the aircraft state data recorded at the time of the exception. The Fault Log provided the following flight plan information at the time of the event:

```
Entered_Cost_Index, 69.0
Cruise_Altitude, 29000.0
Company_Route, "    "
Departure_Airport, "KORD "
Arrival_Airport, "KPIT "
SID_ID, "    "
STAR_ID, "JESEY4"
Approach_ID, "RNVY 28C"
Climb_Mode, Selected_Speed
Cruise_Mode, Selected_Speed
Descent_Mode, Manual_Path
Goto_Lateral_Data_Control, Flyover_Turn_To_Direct
Goto_Path_Capture, Heading_Leg_Update
RTA_Enabled, False
Offset_Status, Non_Offsetable_Flight_Plan
Offset_Start_Waypoint, "-----"
Offset_End_Waypoint, "-----"
Flight_Plan_Waypoints, "ROOSA (VECTOR) @@@@ NESTO "
```

The flight in the lab environment duplicated the event flight. After transitioning from waypoint ROOSA onto the VECTOR (i.e. (VECTOR) became the GO TO waypoint), a dual FMC reset occurred within 1-2 seconds. After approximately 30 seconds, both FMCs recovered (FMC prompt was displayed on the CDUs). The flight plan was retained after the reset, and the discontinuity was closed by line-selecting NESTO.

4.0 FMC Fault Discussion

The VECTOR/Discontinuity (DISCO) combination followed by a waypoint with a Required Navigation Performance (RNP) aligns with the input conditions for a known software exception documented in GE Problem Report (PR) PR453694.

This problem was introduced in the U14 version of the 737 FMS software due to refinements made to the earth model. The software exception occurs in air when a VECTOR is the go to waypoint, followed by a DISCO, followed by a waypoint that has an RNP. The DISCO latitude/longitude (which is 'undefined') is being used as the RNP inferred position by the Navigation (NAV) function. This results in a "numeric_error" exception in the earth model used by the FMC. The software restart logic manages

the restart correctly by demoting cost index and displaying "VNAV INVALID-PERF" message. Upon recovery, the flight plan is demoted from active flight plan to modify (mod) flight plan, with a DISCO inserted at the beginning for crew response to edit the mod plan prior to executing the plan in order to set the appropriate GO TO waypoint. This recovery procedure behavior is described on pages 1-61 and 1-62 of the FMCS FMC Update 14.0 Reference Guide (GE Aviation document RM1230 Revision B).

The software exception documented in PR453694 was introduced in the U14 version of the 737 FMS software and has been fixed in the U14.1 version of the software. GE repeated the incident flight using U14.1 (GE P/N 650630-004) and observed no FMC reset, as expected. GE also repeated the scenario using U13 (GE P/N 5599777-01) and observed no FMC reset, as expected.

GE repeated the scenario with U14 and following the procedural work around documented in the PR (the DISCO should be closed PRIOR to the VECTOR becoming the GOTO waypoint). When this was done, no FMC reset was observed. The work-around provided a smooth transition from the VECTOR to the NESTO approach procedure.

FMC software U14.1 is installed on 737-8, 737-9, 737-8200 Airplane(s) per Boeing Service Bulletin 737-34-3656, dated May 28, 2022. According to Boeing, the Service Bulletin for 737NGs is expected to be released in the third quarter of 2023. Boeing issued Fleet Team Digest articles 737MAX-FTD-34-20002 (April 2022) and 737NG-FTD-34-22005 (August 2022) as well as Service Letter 737-SL-34-251 (February 2020) to operators that discuss the Dual FMC Reset due to VECTOR/DISCONTINUITY and related Service Bulletin release.

Submitted by:

John Flynn
Aerospace Engineer

APPENDIX A FMC FAULT DATA SHEET FILE

FMC 1 (S/N 015170)	FMC 2 (S/N 015168)
Filename: FAULT D.206	Filename: FAULT D.206
Fault Data Sheet Record, 24, "Jun 21, 2022 13:40:12"	Fault Data Sheet Record, 36, "Jun 21, 2022 13:40:12"
FMC ETI Valid, True	FMC ETI Valid, True
FMC ETI, 11368.9000000000	FMC ETI, 11358.6000000000
FMC Serial Number, "15170"	FMC Serial Number, "15168"
Hardware Model, 2907C1	Hardware Model, 2907C1
Hardware Model CPU Frequency, 30	Hardware Model CPU Frequency, 30
OFP Part Number, "650630-00-2 "	OFP Part Number, "650630-00-2 "
Nav Data Base ID, "U737220601"	Nav Data Base ID, "U737220601"
SW Options ID, "BCG-01T-R5"	SW Options ID, "BCG-01T-R5"
Model Engine dB ID, "BCG-01T-A3"	Model Engine dB ID, "BCG-01T-A3"
Flight Plan dB ID, " "	Flight Plan dB ID, " "
Flight Number, "UAL2627 "	Flight Number, "UAL2627 "
Aircraft In Air, True	Aircraft In Air, True
Current Phase, Descent	Current Phase, Descent
LNAV Engaged, True	LNAV Engaged, True
VNAV Engaged, False	VNAV Engaged, False
Aircraft Latitude(Degrees), N40 deg 34.7155 min	Aircraft Latitude(Degrees), N40 deg 34.7155 min
Aircraft Latitude(Radians), 0.708230	Aircraft Latitude(Radians), 0.708230
Aircraft Longitude(Degrees), W80 deg 5.8311 min	Aircraft Longitude(Degrees), W80 deg 5.8167 min
Aircraft Longitude(Radians), -1.397960	Aircraft Longitude(Radians), -1.397955
Wander Angle, 5.191199304	Wander Angle, 5.190516339
MCP Altitude, 4000.0	MCP Altitude, 4000.0
Actual Altitude, 4243.8	Actual Altitude, 4243.5
MCP Speed, 210.0	MCP Speed, 210.0
Ground Speed, 285.2	Ground Speed, 285.2
Magnetic Track, 102.1	Magnetic Track, 102.1
Vertical Speed, -16.8	Vertical Speed, -16.4
Head Wind, -14.5	Head Wind, -14.5
Cross Wind, -9.0	Cross Wind, -8.8
Crosstrack Error, 0.000	Crosstrack Error, 0.000
VTK Error, 5756.3	VTK Error, 5751.8
Flap Position, 0.0	Flap Position, 0.0
Distance To Goto Waypoint, 28.974	Distance To Goto Waypoint, 28.974
Gross Weight, 148.622	Gross Weight, 148.622
Primary Route Num, 1	Primary Route Num, 1
Route Type, Active	Route Type, Active
Current Cost Index, 69.0	Current Cost Index, 69.0
Entered Cost Index, 69.0	Entered Cost Index, -10.0
Cruise Altitude, 29000.0	Cruise Altitude, 29000.0
Company Route, " "	Company Route, " "
Departure Airport, "KORD "	Departure Airport, "KORD "
Arrival Airport, "KPIT "	Arrival Airport, "KPIT "
SID ID, " "	SID ID, " "
STAR ID, "JESEY4"	STAR ID, "JESEY4"
Approach ID, "RNVY 28C"	Approach ID, "RNVY 28C"
Climb Mode, Selected Speed	Climb Mode, Selected Speed
Cruise Mode, Selected Speed	Cruise Mode, Selected Speed
Descent Mode, Manual Path	Descent Mode, Manual Path
Goto Lateral Data Control, Flyover Turn To Direct	Goto Lateral Data Control, Flyover Turn To Direct

FMC 1 (S/N 015170)	FMC 2 (S/N 015168)
Goto Path Capture, Heading Leg Update	Goto Path Capture, Heading Leg Update
RTA Enabled, False	RTA Enabled, False
Offset Status, Non Offsetable Flight Plan	Offset Status, Non Offsetable Flight Plan
Offset Start Waypoint, "-----"	Offset Start Waypoint, "-----"
Offset End Waypoint, "-----"	Offset End Waypoint, "-----"
Flight Plan Waypoints, "ROOSA (VECTOR) @@@@@ NESTO "	Flight Plan Waypoints, "ROOSA (VECTOR) @@@@@ NESTO "
Airways, "JESEY4 (JESEY4) -----"	Airways, "JESEY4 (JESEY4) -----"

APPENDIX B FMC 1 AND 2 TRACEBACK DATA

FMC 1 (S/N 015170)	FMC 2 (S/N 015168)
Filename: PROG FA.212	Filename: PROG FA.212
Program Fault Record, 35, "Jun 21, 2022 13:40:12"	Program Fault Record, 47, "Jun 21, 2022 13:40:12"
FMC ETI Valid, True	FMC ETI Valid, True
FMC ETI, 11368.9	FMC ETI, 11358.6
Fault Count, 1	Fault Count, 1
FMC Restarted, True	FMC Restarted, True
Error Code, 1A1	Error Code, 1A1
DMT Source, "Unsolicited"	DMT Source, "Unsolicited"
Traceback Address, 07386D40	Traceback Address, 07386D40
Traceback_Segment_Name, "MACHINE INTERFACE"	Traceback_Segment_Name, "MACHINE INTERFACE"
Traceback Segment Offset, 0x000000CC	Traceback Segment Offset, 0x000000CC
Traceback Symbol Name, "MI\$ TRUNCATE"	Traceback Symbol Name, "MI\$ TRUNCATE"
Traceback Symbol Offset, 0x0000000E	Traceback Symbol Offset, 0x0000000E
Traceback Address, 07005DB8	Traceback Address, 07005DB8
Traceback Segment Name, "ADA\$ANGLES"	Traceback Segment Name, "ADA\$ANGLES"
Traceback Segment Offset, 0x0000006C	Traceback Segment Offset, 0x0000006C
Traceback Symbol Name, "MOD PI TO PI 201"	Traceback Symbol Name, "MOD PI TO PI 201"
Traceback Symbol Offset, 0x0000002A	Traceback Symbol Offset, 0x0000002A
Traceback Address, 07030EA6	Traceback Address, 07030EA6
Traceback_Segment_Name, "ADA\$EARTH_MODEL.COMPUTE_GROUND_PAT H\$"	Traceback_Segment_Name, "ADA\$EARTH_MODEL.COMPUTE_GROUND_PAT H\$"
Traceback Segment Offset, 0x0000002E	Traceback Segment Offset, 0x0000002E
Traceback Symbol Name, "COMPUTE GROUND PATH 1601"	Traceback Symbol Name, "COMPUTE GROUND PATH 1601"
Traceback Symbol Offset, 0x0000002E	Traceback Symbol Offset, 0x0000002E
Traceback Address, 0702E3AA	Traceback Address, 0702E3AA
Traceback Segment Name, "ADA\$EARTH MODEL\$"	Traceback Segment Name, "ADA\$EARTH MODEL\$"
Traceback Segment Offset, 0x000000AE	Traceback Segment Offset, 0x000000AE
Traceback Symbol Name, "GROUND PATH DISTANCE 601"	Traceback Symbol Name, "GROUND PATH DISTANCE 601"
Traceback Symbol Offset, 0x0000001A	Traceback Symbol Offset, 0x0000001A
Traceback Address, 072B85FA	Traceback Address, 072B85FA
Traceback_Segment_Name, "ADA\$NAV.SYS NAV.MANAGE RNP DISPLAY\$"	Traceback_Segment_Name, "ADA\$NAV.SYS NAV.MANAGE RNP DISPLAY\$"
Traceback Segment Offset, 0x000000E0	Traceback Segment Offset, 0x000000E0
Traceback_Symbol_Name, "MANAGE RNP DISPLAY 3601"	Traceback_Symbol_Name, "MANAGE RNP DISPLAY 3601"
Traceback Symbol Offset, 0x000000E0	Traceback Symbol Offset, 0x000000E0
Traceback Address, 072B848C	Traceback Address, 072B848C
Traceback_Segment_Name, "ADA\$NAV.SYS NAV.SYS NAV CTL\$"	Traceback_Segment_Name, "ADA\$NAV.SYS NAV.SYS NAV CTL\$"
Traceback Segment Offset, 0x00000560	Traceback Segment Offset, 0x00000560
Traceback Symbol Name, "SYS NAV CTL 4901"	Traceback Symbol Name, "SYS NAV CTL 4901"
Traceback Symbol Offset, 0x00000560	Traceback Symbol Offset, 0x00000560
Traceback Address, 072BC6D4	Traceback Address, 072BC6D4
Traceback_Segment_Name, "ADA\$NAV.SYS NAV.SYS NAV MAIN\$"	Traceback_Segment_Name, "ADA\$NAV.SYS NAV.SYS NAV MAIN\$"
Traceback Segment Offset, 0x00000018	Traceback Segment Offset, 0x00000018

FMC 1 (S/N 015170)	FMC 2 (S/N 015168)
Traceback Symbol Name, "SYS NAV MAIN 901"	Traceback Symbol Name, "SYS NAV MAIN 901"
Traceback Symbol Offset, 0x00000018	Traceback Symbol Offset, 0x00000018
Traceback Address, 072BC73E	Traceback Address, 072BC73E
Traceback Segment Name, "ADA\$NAV.SYS NAV.SYS NAV PROCESS\$"	Traceback Segment Name, "ADA\$NAV.SYS NAV.SYS NAV PROCESS\$"
Traceback Segment Offset, 0x00000060	Traceback Segment Offset, 0x00000060
Traceback Symbol Name, "SYS NAV PROCESS 1001"	Traceback Symbol Name, "SYS NAV PROCESS 1001"
Traceback Symbol Offset, 0x00000060	Traceback Symbol Offset, 0x00000060
<<<End Of Record>>>, \$	<<<End Of Record>>>, \$