NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

September21, 2022

Group Chairman's Factual Report

SYSTEMS

ENG20LA016

A. INCIDENT

Location: Sacramento, California
Date: February 15, 2020
Time: 0742 Pacific Daylight Time
Airplane: Spirit Airlines flight 1818, an Airbus A319, Registration number N521NK

B. SYSTEMS GROUP

Group Chairman	Mike Hauf National Transportation Safety Board
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Group Member	Will Webber Collins Aerospace
Group Member	Matt Gorshe Air Line Pilots Association

C. FACTUAL INFORMATION

1.0 Components Removed

On February 17th, 2020, Spirit Airlines removed several electrical system components from the airplane as part of their troubleshooting process (see Table 1). At the request of the NTSB, these components were photographed and then placed into quarantine at a Spirit Airlines maintenance facility located in Las Vegas, Nevada.

Table 1 Components recovered from the airplane

COMPONENT	PART NUMBER	SERIAL NUMBER
Integrated Drive Generator #1	772292	1266
Integrated Drive Generator #2	772292	1157
Generator Control Unit #1	767584K	AAAY013617
Generator Control Unit #2	767584J	AAAY003683
#2 Bus Tie Circuit Breaker	558CA04A30Y00	30959
Ground Auxiliary Power Control Unit	1700667D	AADU003342

2.0 Electronic Centralized Aircraft Monitoring (ECAM) System Description

The Airbus A319, in common with other Airbus aircraft, is equipped with an electronic instrument system (EIS). This system consists of six liquid crystal cockpit display units (DU), two displays in front of each pilot and two central displays. The upper display is the Engine and Warning Display (EW/D), the lower display is the System. The pilot displays are part of the electronic flight instrument system (EFIS) and provide primary flight instrumentation information on the primary flight display (PFD) and the navigation display (ND). The PFDs present information on aircraft attitude, performance, flight path and autopilot modes and the NDs provide navigation, weather radar and Traffic alert and Collision Avoidance System (TCAS) information.

The System Display (SD) has the capability to display 13 different system pages, the cruise page or the status page. The display has two areas: the upper section of the screen provides information based on the selection of the display, and the lower section contains permanent data that is always present regardless of the page selection. This permanent data contains information on the total and static outside air temperatures, the time, the aircraft's gross weight and its center of gravity. In flight, the 'default' cruise page is generally displayed. This page shows additional engine parameters, such as fuel burn, oil quantity and vibration levels, as well as cabin air and pressurization parameters.

The lower ECAM display unit normally provides the "System Display", which presents synoptic diagrams showing the status of various aircraft systems. The

ECAM display is controlled through the ECAM Control Panel (ECP), located on the center pedestal directly below the ECAM displays.

A specific system page such as the "ELEC System" may be called up manually, by selection of the appropriate button on ECP; a page will appear automatically following an aircraft system failure.

For both the synoptic diagrams and the control panel captions, normal system conditions are displayed in green or white and abnormal conditions in amber. Several fault conditions also cause the red Master Warning or amber Master Caution lights on the flight deck to illuminate and a continuous or single chime to sound.

3.0 Electrical Power System Description

The electrical power system (EPS) consists of a three-phase 115/200 V 400 Hz constant-frequency AC system and a 28 V DC system.

The EPS comprises two electrical networks, a left and a right, denoted AC BUS 1 and AC BUS 2. There is also a third network, called the "AC Essential' (ESS) Bus, which is supplied by either AC BUS 1 or AC BUS 2; the AC ESS BUS supplies power to most of the critical aircraft systems.

The AC BUS 1 and AC BUS 2 networks are normally independent of one another, so that the failure of one network should not affect the other. The power supplies for flight critical systems are for the most part segregated, so that the loss of a single power source should not cause concurrent failures of systems necessary for continued safe flight.

The EPS also comprises a third generator (APU GEN) that is driven directly by the Auxiliary Power Unit; it produces the same electrical output as each of the main engine generators. Additionally, a ground power connector near the nosewheel allows ground power to be supplied to all busbars. A ground and auxiliary power control unit (GAPCU) regulates the frequency and voltage of the APU generator; it also protects the network by controlling the external power contactor and the APU generator line contactor.

In the event of loss of AC BUS 1 or AC BUS 2 in flight, both Bus Tie Contactors (BTC) are automatically closed by relay logic, allowing the affected network to be powered by the generator on the opposite side. In this condition, one engine-driven generator supplies power to both electrical networks.

In the event of loss of both the AC BUS 1 and AC BUS 2 busbars in flight, vital services can be fed by an AC 5 kVA Emergency Generator which is driven by the RAT. The RAT deploys either automatically, usually because of loss of both main AC busbars or by manual selection. RAT deployment is indicated by a green icon on the ECAM hydraulic system page.

The electrical system is controlled via the electrical panel located on the overhead console in the cockpit. This panel provides for annunciation of the status of the electrical system and fault conditions. The generator control switches[1] are identified as GEN 1, GEN 2 and APU GEN for the left, right and APU generators. If a fault occurs with a generator, an amber fault message will illuminate on the respective generator control push button (PB) switch indicating the channel is offline. For a generator fault, pressing the PB once turns the generator to OFF. Pressing the PB a second time is required to reset the generator back to ON.

3.1 Integrated Drive Generators

Two engine-driven AC generators (GEN 1 & GEN 2), one mounted on each engine, normally power the EPS system. Each generator is driven from the engine high-pressure spool via an engine accessory gearbox and an integrated hydro-mechanical speed regulator. The regulator transforms variable engine rotational speed into a constant-speed drive for the generator. The constant-speed drive and the generator together form an assembly known as an Integrated Drive Generator (IDG).

3.1.1 Cylinder Blocks

As part of the IDG, the pump and motor assembly provide trim to the gear differential that converts a variable input speed into a constant output speed. Within the pump and motor assembly are two cylinder blocks, one fixed and one variable. Each cylinder block includes nine cylindrical bores with pistons fitted inside each bore. On the inside of each bore is a brass sleeve which is secured inside the cylinder by a proprietary process.

The fixed and variable cylinder blocks work together, using the flow of hydraulic fluid and a governor, to produce a constant output speed. As the hydraulic fluid moves through the cylinder blocks, the pistons move within each of the nine cylinders. Over time, the movement of the pistons causes the brass sleeves to wear.

[1] The selectors on the panel consist of alternate-action push-button selector switches, whereby consecutive pushes cycle the switch between the ON and OFF settings.

3.1.2 Maintenance of Cylinder Blocks

The brass sleeves within the cylinder blocks wear over time and are considered sacrificial; the brass sleeve is sacrificed as part of the normal operation. Therefore, normal, maintenance of the IDG and cylinder blocks calls for the replacement of the pistons with slightly larger (in diameter) pistons to better fill the bores.

The sleeves are replaced as part of normal periodic maintenance of the IDGs. Spirit Airlines, as part of their maintenance practices, contracted with Lufthansa Technik to provide IDGs and maintain their stock of A319 IDGs as an exchange program. The contract allowed for Spirit to send Lufthansa Technik IDGs for servicing and Lufthansa Technik would provide Spirit with refurbished, serviced IDGs for installation.

Lufthansa Technik would service the IDGs at their facility in Hamburg, Germany. As part of the servicing, the cylinder blocks would be removed and replaced with refurbished cylinder blocks. Lufthansa Technik was provided with refurbished cylinder blocks by Aircraft Component Repair in California.

For more information regarding the refurbished cylinder blocks and examination of the cylinder blocks, please refer to the Maintenance Factual Report and Material Laboratory Report of Examination.

Lufthansa Technik provided information related to the maintenance of the two IDGs removed from the incident airplane. According to Lufthansa Technik, serial numbers 1266 and 1157 (IDGs 1 and 2, respectively), had been returned to them several times for maintenance. As part of the normal maintenance, the IDG cylinder blocks had been replaced. For IDG serial number 1266, the cylinder block had most recently been replaced in September 2017. For IDG serial number 1157, the cylinder block had most recently been replaced in March 2017.

3.2 Generator Control Units

Two generator control units (GCU) control the output of their respective generator. The main functions of the GCUs are to control the frequency and voltage of the generator output and to protect the network by controlling the associated generator line contactor (GLC).

The airplane is also fitted with a GCU dedicated for the operation of ground power and the auxiliary power unit (APU), referenced as the GAPCU.

Software resident in the GCUs is used to monitor and control the generators (IDG) for each electrical channel. The GCU has authority to take an IDG off-line if the software monitors detect a fault with the operation or output of the IDG. The GCU records the fault in the internal memory in addition to sending the fault information to the airplane's maintenance system.

4.0 Examination of Generator Control Units:

On March 13, 2020, at the request of the NTSB, the following components were shipped from Spirit Airlines to the Collins Aerospace facility located in Phoenix, Arizona and placed into a secured area.

1. Generator Control Unit, Position Number 1
   Part Number: 767584K
   Serial Number: AAAY013617
   Date of Manufacture: 112014
   Modification Status: 1-7,9-12, 16

2. Generator Control Unit, Position Number 2
   Part Number: 767584J
   Serial Number: AAAY003683
   Date of Manufacture: 102006

3. Ground & Auxiliary Power Control Unit (GAPCU)
   Part Number: 1700667D
   Serial Number: AADU003342
   Date of Manufacture: 052008

On May 5, 2020, at the request of the NTSB, Collins Aerospace then shipped these three components from their facility located in Phoenix, Arizona to their facility located in Rockford Illinois and placed into a locked and secured area.

On May 13, 2020, Collins Aerospace performed a download of the non-volatile memory (NVM) from these three components at their facility located in Rockford Illinois in the presence of an FAA inspector and with the group participants witnessing the examination virtually via WebEx. For each unit examined, the general condition of the unit was visually assessed and documented.

In the presence of an FAA representative, Collins retrieved the shipping containers (3) with the components identified in Table 2 from a locker storage unit. The shipping containers were brought down to the New York conference room at the RFD Collins facility. The FAA verified that all three cases had zip ties securing the case latch.

Collins, at the request of the NTSB, shipped the two GCUs from their Rockford, facility to the Airbus facility in Toulouse, France for electrical system testing and simulation that were conducted in October 2020.

At the completion of the Airbus testing, on December 7, 2020, at the request of the NTSB, Collins Aerospace shipped these two components from the Airbus facility in Toulouse, France back to their facility located in Phoenix, Arizona for further examination.

The Systems group met, virtually and in-person, at the Collins facility in Phoenix, Arizona on February 23, 2021, to examine the airplane's two generator control units removed from the incident airplane. When the group gathered, the components were removed from their shipping boxes and inducted into the Collins component tracking system. As part of the induction process, each unit was examined, the general condition of the unit was visually assessed, and photo documented as necessary.

4.1 Examination - Ground and Auxiliary Power Control Unit (GAPCU):

4.1.1 NVM Data Download - Rockford:

- The shipping container was opened in the presence of the group participants and the GAPCU (encased within a plastic bag) was removed from the container.
- The part number and serial number listed on the unit's data plate were consistent with the information previously provided by Spirit Airlines and with the paperwork provided with the unit.
- Overall, the GAPCU was in good condition, no visual external damage was observed, only a darkened patch on the bottom of the chassis. The back right side had an unbroken Hamilton Sundstrand security sticker in place.
- "Lufthansa Technic" security tape had been placed over the upper plastic cap that was protecting the electrical connector. The tape and plastic caps were removed so the electrical connector could be inspected. The electrical connector was found undamaged, and no debris or contamination was observed within the pin holes.
- The unit was electrically connected to Collins's engineering equipment which was able to power the GAPCU and communicate with it.
- The first attempt to interface with software did not go successfully.
- A test box was slaved in to check the functionality of the GSE and was found functional.
- The second attempt was successful and the NVM was downloaded into Collins computer network.
- After the download was completed, the unit was placed back into its shipping container and its latch was re-secured with a zip tie.

- The data was downloaded into a text file. (Attachment 1)

4.1.2 Examination in Phoenix:

1. Removal from Shipping Container and Visual Inspection:

   The GAPCU was removed from its shipping container and was visually examined. The GAPCU's part and serial numbers were confirmed. The exterior was noted to be in good physical condition and no damage noted.

2. Download of the Nov-Volatile Memory:

   The GAPCU was attached to a Collins automated test equipment bench. As part of the ATP, the information recorded in the unit's non-volatile memory was accessed and downloaded. The information was compared to the information downloaded during the previous download effort on May 13, 2020.

3. Acceptance Test Protocol of the GAPCU"

   The Collins Acceptance Test Protocol, as denoted in the Component Maintenance Manual (CMM 24-41-12), was accomplished on the GAPCU. The ATP was completed on the GAPCU with no faults found.

4.2 Generator Control Unit Number 2 - AAAY003683:

4.2.1 NVM Data Download - Rockford:

- The shipping container was opened in the presence of the group participants and the GCU (encased within a plastic bag) was removed from the container.
- The part number and serial number listed on the unit's data plate were consistent with the information previously provided by Spirit Airlines and with the paperwork provided with the unit.
- Overall, the GCU was in good condition, no visual damage was observed. The left side had an unbroken Hamilton Sundstrand security sticker in place.
- "Lufthansa Technic" security tape had been placed over the plastic cap that was protecting the electrical connector. The tape and plastic caps were removed so the electrical connector could be inspected.
- The electrical connector was found undamaged, and no debris or contamination was observed within the pin holes.

- The GCU was electrically connected to Collins engineering equipment[2] and its NVM (198 fault codes) was downloaded into a text file. (Attachment 2)
- After the download was completed, the unit was placed back into its shipping container and the latch was re-secured with a zip tie.

4.2.2 Examination in Phoenix

1. Removal from Shipping Container and Visual Inspection

   The GCU was removed from its shipping container and was visually examined. The GCU's part and serial numbers were confirmed. The exterior was noted to be in good physical condition and no damage noted.

2. Download of Non-Volatile Memory

   The GCU was attached to a Collins automated test equipment bench. As part of the ATP, the information recorded in the unit's non-volatile memory was accessed and downloaded. The information was compared to the information downloaded during the previous download effort on May 13, 2020. The download also confirmed the use of the GCU during the Airbus testing in October 2020.

3. Acceptance Test Protocol of the GCU

   The Collins Acceptance Test Protocol, as denoted in the Component Maintenance Manual (CMM 24-23-23), was accomplished on the GCU. The ATP was completed on the GCU with no faults found.

4.3 Generator Control Unit #1 - AAAY013617

4.3.1 NVM Data Download

- The shipping container was opened in the presence of the group participants and the GCU (encased within a plastic bag) was removed from the container.
- The part number and serial number listed on the unit's data plate were consistent with the information previously provided by Spirit Airlines and as shown in table 1 above)

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[2] When connected to a test unit (GCU or GAPCU), the Collins Engineering test equipment is able to power on and communicate with the unit allowing NVM data to be downloaded,

- The top back of the chassis was visibly bent down by the two assembly screws. Otherwise, the GCU was in good condition. The right side had an unbroken Lufthansa Technik security sticker in place.
- ESD tape had been placed over the plastic caps that were in-place and protecting the electrical connector. The tape and plastic caps were removed so the electrical connector could be inspected.
- The electrical connector was found undamaged, and no debris or contamination was observed within the pin holes.
- The GCU was electrically connected to Collins engineering equipment[3] and its NVM (321 fault codes) was downloaded into a text file. (Attachment 3)
- After the download was completed, the unit was placed back into its shipping container and the latch was re-secured with a zip tie.

4.3.2 Examination in Phoenix

1. Removal from Shipping Container and Visual Inspection

   The GCU was removed from its shipping container and was visually examined. The GCU's part and serial numbers were confirmed. The exterior was noted to be in good physical condition and no damage noted.

2. Download of Non-Volatile Memory

   The GCU was attached to a Collins automated test equipment bench. As part of the ATP, the information recorded in the unit's non-volatile memory was accessed and downloaded. The information was compared to the information downloaded during the previous download effort on May 13, 2020. The download also confirmed the use of the GCU during the Airbus testing in October 2020.

3. Acceptance Test Protocol of the GCU

   The Collins Acceptance Test Protocol, as denoted in the Component Maintenance Manual (CMM 24-23-23), was accomplished on the GCU. The ATP was completed on the GCU with no faults found.

4.4 NVM Fault Code 145:

According to Collins, the GCU provides system monitoring and protection and will automatically turn off the electric power generating channel when design parameters are exceeded. As part of the system monitoring, the GCU will

[3] When connected to a test unit (GCU or GAPCU), the Collins Engineering test equipment will power on and communicate with the unit allowing NVM data to be downloaded.

identify and record pre-determined fault codes (along with date/time) into the non-volatile memory. One of the fault codes, Fault 145, requires frequency modulation with divergence and duration outside specified limits. This fault was designed to stop system operation in the case of a failing servo valve. The servo valve is an electro-mechanical device which plays a role in frequency control.

The NVM download revealed that GCU1 (Channel 1) and GCU 2 (Channel 2) had recorded fault code 145 multiple times (See table 2).

Table 2 GCU fault codes

Date	Time	GCU	Fault Code	Flight Phase	Fault Status
1/19/2020	22:56:06	1	145	09	INACTIVE
1/23/2020	04:12:18	1	145	09	INACTIVE
1/29/2020	00:37:42	1	145	09	INACTIVE
2/14/2020	21:15:48	2	145	06	INACTIVE
2/14/2020	21:16:00	1	145	06	INACTIVE
2/15/2020	15:41:48	2	145	06	INACTIVE
2/15/2020	15:42:00	1	145	06	INACTIVE

Collins Aerospace reviewed the NVM data and noted the following:

- January Flights:
  - For the three flights in January in which fault code 145 was recorded, the faults occurred after landing during a single-engine taxi placing all of the aircraft electrical load on channel 1.
  - No other flights in January produced fault code 145.
- February 14, 2020, flight
  - Channel 2 tripped at normal load as fault 145
  - Channel 1 load doubled after channel 2 drops offline
  - Channel 1 tripped as fault 145
  - Both channels record input speed near straight-thru speed realm
  - Frequencies consistent with fault 145
  - Servo valve current readings nominal
  - Oil temperatures nominal
- February 15, 2020, flight (Event), in chronological order(?)
  - Channel 2 tripped at normal load as fault 145
  - Channel 1 load doubled after channel 2 drops offline
  - Channel 1 tripped as fault 145 twelve seconds after channel 2 went offline.

- Both channels record input speed near straight-thru speed realm
- Frequencies consistent with fault 145
- Servo valve current readings nominal
- Oil temperatures nominal

5.0 Examination of Integrated Drive Generators

The Systems group met at the Collins facility located in Miramar, Florida from September 15-17, 21-22 2020 to examine the Number 1 & 2 Integrated Drive Generators (IDG) that had been removed from the incident airplane. The IDG's were identified as follows:

1. IDG1
   Part Number: 772292
   Serial Number: 1266

2. IDG2
   Part Number: 772292
   Serial Number: 1157

5.1 Examination of IDG1

After IDG1 was removed from its shipping container, a visual inspection was conducted, and the following details were noted:

- The exterior was noted to be in good physical condition. Some exterior areas were noted with missing/worn paint, which Collins indicated was normal wear.
- The vacuum vent valve screen was missing.
- The IDG has a sticker affixed near the oil fil port that stated "Use Mobil Jet 2 Oil"

Following the visual inspection, the IDG was installed onto a Collins IDG Test Stand in preparation for functional testing. The Collins Acceptance Test Protocol, noted as Component Maintenance Manual (CMM) Task 24-11-89-99F-811-1, was accomplished on the IDG.

1.0 Static Electrical Test

All tests were within limits/passed.

2.0 Oil Sample

An oil sample of approximately 6 oz was taken from the IDG and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found the oil to be consistent with MobilJet II turbine oil, with no contaminating substances (fuel, Skydrol, etc.) detected. The oil was relatively clean showing generally normal wear combined with foreign debris consistent with the finding of damaged block bores.

3.0 Water Tank Test

The IDG was charged with air to 20psi and then immersed into a water tank to check for IDG leaks. No bubbles were noted leaking from the unit; the test was considered passed.

4.0 Charge Filter

The charge filer was removed and inspected; the filter appeared normal with no contaminants noted on the filter surface. The bowl, cavity and barrel all appeared normal. The filter was placed in a plastic bag, labeled, and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found that the filter displayed a small amount of damage (denting) to its exterior metal mesh.

5.0 Scavenge Filter

The scavenge filter was removed and appeared normal with no contaminants on the filter. The bowl and barrel all appeared normal, however, two small pieces of metal, both the size of a grain of sand, copper in color was on the bottom of the cavity. The filter and metal were placed in a plastic bag, labeled, and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found that the filter displayed a small amount of damage (denting) to its exterior metal mesh. The material properties of the metal were different from material used by Collins.

6.0 Pressure Filter Test

The Pressure Filter Test was not performed, per group consensus, to ensure no particulates and/ or contaminants were not flushed out of the unit.

7.0 Dynamic Testing

It was determined that the test stand was not representative of its mounting orientation on the actual airplane. The IDG was canted 3 degrees about the roll axis. Collins could not determine the correction to reading the oil level sight gauge at the time of testing. It was decided to fill the unit to the top of the green band and proceed to dynamic testing.

The IDG exhibited noticeable vibration at high speed (9000 rpm) under 0 or low load.

The IDG vibration increased as the load was increased. At a load of 45kw, the test cell operator became very concerned of the level of vibration and noise emanating from the IDG. It was determined it would be unsafe to apply an additional load on the IDG as it could of lead to damage or failure of the IDG.

A no load test was performed and the IDG Failed. The unit also failed at 23kw and 45kw under a constant speed. A 90kw load was not applied due to safety concerns

Slow Acceleration tests were performed at 50/100/150rpm/sec/sec. The IDG passed all 0 and 23kw tests. The IDG failed all slow acceleration tests at 45kw.

A slip test was performed and passed. The ATP test was not completed in its entirety due to safety concerns. The Airbus Specific Test plan (2.2.4) was not completed in its entirety on the IDG. All tests were recorded and graphed by Collins

The conditions at the time of failure were accurately replicated and it was determined that the IDG would generate a FC145 failure code.

8.0 Teardown

Upon disassembly of the IDG, it was observed that the fixed hydraulic cylinder blocks had been modified by a non-OEM process[4] and was marked as PN CB-31773. Visual inspection of the fixed blocks revealed that portions of the Number 3 and 5 bronze bore lining were missing, having flaked off after wearing thin. There was approximately 1/4 to 1/3 of the bore missing in the Number 3 and Number 5. Several "flecks" of metal, copper in color were noted in the block assembly. The fixed-block was shipped to Rockford, IL and subsequently to the NTSB lab for further metrology.

The fixed block and pistons were replaced with OEM parts and reinstalled into the IDG. The IDG was reassembled and prepared for additional testing.

9.0 Dynamic Re-Testing

The IDG was subject to several retests. The unit passed a no-load test, a 4795 rpm load test at 0, 23, 45 and 90kw and the same loads at 9000rpm

The IDG was subject to a slow acceleration test at 50rpm/sec/sec at 0, 23, 45

[4] The process was approved by the FAA. See Maintenance Factual Report and Materials Lab Factual Report for further information.

and 90kw and passed.
The maximum deviation was approximately 0.5hz.
The unit did not vibrate to any degree compared to the initial testing and it was determined by group consensus that the cause of the failure was identified and corrected, and no further testing was necessary.

At the conclusion of the IDG#1 testing, the following items were removed from the unit:
1. Oil Sample
2. Filter
3. Patch Filter
4. Pistons
5. Cylinder Block

5.2 Examination of IDG2

The IDG was not shipped in its proper shipping container. It was in a secure cardboard box strapped on a pallet. There was oil observed spilled out from the IDG on to the pallet. After it was removed from its shipping container, a visual inspection was conducted, and the following details were noted:
- The IDG was examined and verified as SN1157.
- The exterior was noted to be in generally good condition with a gouge mark on the top of the unit.
- The IDG was shipped without the oil port caps installed.
- The IDG has a sticker affixed near the oil fil port that stated "Use Mobil Jet 2 Oil"

Following the visual inspection, the IDG2 was installed onto a Collins IDG Test Stand in preparation for functional testing. The Collins Acceptance Test Protocol, noted as Component Maintenance Manual (CMM) Task 24-11-89-99F-811-1, was accomplished on the IDG.

1. <u>Static Electrical Test</u>
   The unit failed the Temperature Bulb Test. All other static tests were passed.

2. <u>Oil Sample</u>
   An oil sample of approximately 6 oz was taken from the IDG and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found the oil to be consistent with MobilJet II turbine oil, with no contaminating substances (fuel, Skydrol, etc.) detected. The oil was

relatively clean showing generally normal wear combined with foreign debris consistent with the finding of damaged block bores.

3. Water Tank Test
   The unit was charged with air to 20psi. Initially there was a few bubbles observed leaking slowly, approximately 1 small bubble per 10 seconds coming from the input shaft seal. The unit was raised out of the tank and the shaft was rotated and the leak stopped.

4. <u>Charge Filter</u>
   The charge filer was removed from the IDG, and it visually appeared normal with no contaminants observed on the filter. The filter bowl appeared normal, but several metal flecks, copper in color were observed in the cover. The filter and metal flecks were placed in a plastic bag, labeled, and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found that the filter displayed a small amount of damage (denting) to its exterior metal mesh. The material properties of the metal flecks was consistent with copper alloy (similar to tin bronze).

5. <u>Scavenge Filter</u>
   The scavenge filer was removed and appeared normal with no contaminants on the filter. The bowl and cover all appeared normal. Four small pieces of metal, copper in color was on the bottom of the cavity. The filter and metal were placed in a plastic bag, labeled, and shipped to the Collins Aerospace facility located in Rockford Illinois for analysis. Results of the analysis found that the filter displayed a small amount of damage (denting) to its exterior metal mesh. The material properties of the metal flecks was consistent with copper alloy (similar to tin bronze), which were different from material used by Collins.

6. <u>Pressure Filter Test</u>
   The Pressure Filter Test was not performed, per group consensus, to ensure no particulates and/ or contaminants were not flushed out of the unit.

7. <u>IDG 2 Dynamic Testing</u>
   - It was determined that the test stand was not representative of its mounting orientation on the actual airplane. The IDG was canted 3 degrees about the roll axis. It was decided to fill the unit to the top of the green band and proceed to dynamic testing.
   - A no load test was performed and passed.
   - Low speed testing was performed at 4975 and passed at loads of 0, 45 and 90kw.
   - An overload test was performed and failed on the first attempt. A second

attempt was performed and the unit passed.

- Slow Acceleration tests were performed at 50rpm/sec/sec. The IDG passed the 0, 23 and 45kw tests.
- A slip test was performed and passed.
- The Airbus Specific Test plan (2.2.4) was not completed in its entirety on the IDG.
- All tests were recorded and graphed by Collins. All of the tests were to be uploaded to the Accellion website.
- The conditions at the time of failure were not able to be clearly replicated. Tests results showed that it was close to the parameters to generate a FC145, but not above the limit. The unit failed the standards set forth in the ATP, but not enough to for the Generator Control Unit (GCU) to theoretically trip the IDG with a FC145.

8. Teardown and Dis-Assembly

As IDG2 testing did not result in output signal distortion that would have caused the GCU fault code to be annunciated, the group decided not to teardown IDG2 as part of the group activities. Rather, the group decided to preserve the "as is" condition of the IDG and place the unit under further dynamic test.

The IDG was sent to Airbus Toulouse facility for further dynamic testing. See Section 6.

5.2.1 Further IDG2 Examination Following Airbus Testing:

On January 6-7, 2021, the group reconvened, virtually and in person, to further examine IDG2[5], including final teardown. The examination was conducted at the Collins Aerospace facility in Miramar, Florida.

During the teardown, Collins noted (at least two) plastic zip ties used as wire bundle stays. Collins noted that zip ties were unapproved as replacement parts for the IDGs.

The following was noted during the teardown of IDG2:

- The spline looked normal, no visible damage.
- Torque on internal port plate screws were above minimum
- The wobbler controller screw torque was measured and was normal.

[5] Prior to the IDG2 examination, Collins verified that IDG1 was missing washers on the terminal blocks and confirmed that the vent screen was missing.

- The fixed cylinder block was removed, and the part number Y04-232-44 was confirmed.
- The block face looked normal and was inscribed with "CB 31773"
- Peeling bronze liner was noted in Bore 4.
- Eight of the pistons were sized A17, one A17-1
- The variable block was noted as serial number Y08-60-45. All pistons were noted as A17.

A new fixed cylinder block was installed into IDG2 and the IDG placed into the Collins IDG test stand. Several of the ATP test runs were performed on the IDG. The following was noted:

- Passed Table 1016 tests at 0, 45, and 90 KVA
- Passed Table 1017 Frequency load test
- Passed Table 1020 test
- Passed Table 1007 Slip Test
- Also passed DPI and Disconnect Tests

Following the tests to IDG2, the fixed cylinder block and associated pistons were held by the NTSB for further material testing. The parts were originally sent to the Collins Rockford facility and then to the NTSB Materials Laboratory in Washington, DC.

6.0 Further Testing of IDGs at Airbus, October 2020

Following the initial examination of the IDGs at Collins in September 2020, the group agreed to conduct further testing of the components at a systems level. Both IDG's, along with the airplane's associated GCUs, were sent to the Airbus facility in Toulouse, France for further testing in October 2020. This testing allowed the individual IDG and GCU to be tested together as a system. In addition, the Airbus test stand allows the use of the flight data recorder (FDR) information to drive the time history dynamic of the IDG/GCU combination.

The testing was conducted at a systems level by operation of both IDGs, with their respective GCUs, and placing the IDGs under test. The test bench was able to monitor the output of each IDG.

The purpose/goal of the tests were to replicate the incident flight conditions, and to generate the Fault 145 condition. There were two events of electrical emergencies on the incident aircraft: one during flight NK806 and the other on flight NK1818. The Trouble Shooting Data (TSD) analyses showed that the following Fault Code (FC) was triggered during both events: FC 145 – Servo Valve MODULATION. The purpose of the testing at Airbus is to reproduce the failure in different configurations of IDG speed and IDG load. The tests were performed as defined by Airbus.

Tests performed on IDG2 found that it exhibited a significant frequency modulation on the IDG electrical output. However, the 145 fault could not be reproduced despite a significant exploration effort performed in order to try to reach the fault trigger conditions.

Nevertheless, several tests showed that the fault was almost triggered under the following conditions:

- A constant speed (or a slow sweep profile) between 6,100 and 6,150 RPM
- A high IDG load that seems to increase slightly the modulation amplitude

The following elements does not seem to be significant contributors to the frequency modulation observed:

- cycling electrical load
- IDG oil temperature
- IDG oil level

The tests on the IDG1, which was fixed at the hydraulic block level, showed that the frequency modulation had disappeared. The frequency modulation has an impact on driving group speed:

- Frequency modulation translates a difficulty of the drive motor to drive accurately the electrical generator at a constant speed.

A torque modulation due to IDG frequency variations translates a speed modulation on the drive motor shaft. Such torque modulation will induce an impact on the drive chain (with a response that depends on the drive chain mechanical characteristics such as its inertia, its stiffness, etc…). Here it produces speed fluctuations (too fast fluctuations to be compensated by the driving group close loop control).

Potential reason explaining the difference between lab results and the events experienced during in-flight operation:

- The torque fluctuation induced by the IDG frequency modulation may have been amplified on aircraft with the real mechanical response of the IDG drive chain compared to the rig where the drive chain is not mechanically representative. This could explain why the event was not reproduced in the lab even if the frequency modulation phenomenon has been clearly identified
- The Bench does not reproduce the entire IDG environment such as the engine vibration environment and the aircraft dynamic behavior. Even if

these factors are most probably not the root cause of the event but may have been a contributor.

The tests were unable to replicate the incident flight conditions.

After the Airbus testing was completed, the units were returned to the Collins facility in Miramar, FL.

7.0 Further examination of Cylinder Blocks

7.1 Collins examination at Rockford of Cylinder Blocks

The cylinder blocks were sent from the Collins facility in Miramar, Florida to the Collins facility in Rockford, Illinois for further documentation of the cylinder block bores and sleeve wear. The sleeves were documented using a Mahr Form Tester to measure the cylindricity of the bores and worn sleeve/liner material.

7.2 Examination at NTSB of Cylinder Blocks

Following the Collins examination at their Rockford, Illinois facility, the cylinder blocks were sent to the NTSB Materials Laboratory in Washington, DC for further examination. The examination included sectioning of the block. See Materials Lab Factual report for further details.

D. LIST OF ATTACHMENTS

Attachment 1 – NVM data – GAPCU
Attachment 2 – NVM data – GCU #2
Attachment 3 – NVM data – GCU #1

Submitted by:

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