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

October 1, 2020

MAINTENANCE RECORDS AND POWERPLANT GROUPCHAIRMAN'S FACTUAL REPORT

NTSB No: ERA17MA316

A. ACCIDENT

Operator:	Air Methods Corporation
Aircraft:	Airbus Helicopters Deutschland GmbH MBB-BK 117 C-2, registration number N146DU
Location:	Hertford, North Carolina
Date:	September 8, 2017
Time:	1120 Local Time

B. GROUP MEMBERS

Maintenance:	Gregory Borsari National Transportation Safety Board Washington, D.C.
Powerplant:	Pierre Scarfo National Transportation Safety Board Washington, D.C.
Director of Operations:	Jason Quisling Air Methods Corporation Greenwood Village, Colorado

TABLE OF ACRONYMS

A/C	Aircraft
AAIP	Approved Aircraft Inspection Program
AC	Advisory Circular
AD	Airworthiness Directive
AGB	Accessory Gearbox
Al	Aluminum
ALF	Aft Looking Forward
AMC	Air Methods Corporation
AMM	Airplane Maintenance Manual
AMT	Accelerated Mission Testing
ATC	Air Traffic Control
BEA	Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile
BTU	British Thermal Unit
C	Carbon
°C	Celsius
CAD	Cautions and Advisory Display
CFR	Code of Federal Regulations
Cr	Chromium
CSN	Cycles Since New
CSO	Cycle Since Overhaul
cSt	Centistoke
CT	Corrected Concentration
Cu	Copper
EDS	Energy Dispersive X-Ray Spectroscopy
EMM	Engine Maintenance Manual
EMP	Electrical Magnetic Plugs
ESN	Engine Serial Number
EtQ	EtQ™ Reliance Quality Management System
°F	Fahrenheit
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FCU	Fuel Control Unit
Fe	Iron
FM	Flight Manual
FMPM	Field Mechanic Procedures Manual
FSDO	Flight Standards District Office
g	Gram
GMM	General Maintenance Manual
GOM	General Operations Manual
HNVGO	Helicopter Night Vision Goggle Operations
HP	High Pressure
HTS	High Thermal Stability
IN	Information Notice
kg	Kilogram

KOH	Potassium Hydroxide
l	Liter
l/hr	Liter per Hour
LOX	Liquid Oxygen
MEL	Minimum Equipment List
Mg	Milligram
Mg/hr	Milligram/Hour
MIL-PRF	Military Performance
ml	Milliliters
MM	Maintenance Manual
mm	Millimeter
MMP	Mechanical Magnetic Plugs
Mn	Manganese
Mo	Molybdenum
N1	Gas Generator Rotational Speed in % RPM
N1*	Gas Generator Rotational Speed in % RPM Computed
N2	Power Turbine Rotational Speed in % RPM
N2*	Power Turbine Rotational Speed in % RPM Computed
NC	North Carolina
NGV	Nozzle Guide Vane
Ni	Nickel
NiCad	Nickel Cadmium
NTSB	National Transportation Safety Board
NVG	Night Vision Goggles
NVIS	Night Vision Imaging System
OEI	One Engine Inoperative
OP	Optional
OpsSpecs	Operations Specifications
oz	Ounces
P	Phosphorus
P2	Compressor Outlet Pressure
PN	Part Number
ppm	Part Per Million
psid	Pounds per Square Inch Differential
R	Required
RGB	Reduction Gearbox
ROOT	Record of Oil Type
RPM	Revolutions Per Minute
RULER™	Remaining Useful Life Evaluation Routine
S	Sulfur
SAFRANHE	Safran Helicopter Engines
SAIB	Special Airworthiness Information Bulletin
SB	Service Bulletin
SDR	Service Difficulty Report
SEM	Scanning Electron Microscope/Scanning Electron Microscopy
SHP	Shaft Horsepower

Si	SILICONE
SL	SERVICE LETTER
SN	SERIAL NUMBER
SOAP	SPECTROMETRIC OIL ANALYSIS PROGRAM
STC	SUPPLEMENTAL TYPE CERTIFICATE
TAN	TOTAL ACID NUMBER
TBO	TIME BETWEEN OVERHAUL IN HOURS
TC	TYPE CERTIFICATE
TCDS	TYPE CERTIFICATION DATA SHEET
TSN	TIME SINCE NEW IN HOURS
TSO	TIME SINCE OVERHAUL IN HOURS
V	VANADIUM
V	VOLUME
W	TUNGSTEN

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C. SUMMARY

On September 8, 2017, about 1120 eastern daylight time, an Airbus Helicopter Deutschland GmbH (formerly Eurocopter Deutschland GmbH)[1] MBB-BK 117 C-2 helicopter, registration number N146DU, powered by two Safran Helicopter Engines (formerly Turbomeca) Arriel 1 E2 turboshaft engines was destroyed when it crashed on a wind turbine farm in Hertford, North Carolina (NC). The commercial pilot, two flight nurses, and one patient were fatally injured. Day visual meteorological conditions prevailed at the time, and a company flight plan was filed for flight that departed the Sentara Albemarle Regional Medical Center Heliport (NC98), Elizabeth City, NC at about 1108 eastern daylight time (local). The flight was destined for the Duke University North Heliport (NC92), Durham, NC. The helicopter was operated by Air Methods Corporation (AMC) under the provisions of 14 *Code of Federal Regulations* (*CFR*) Part 135.

D. DETAILS OF INVESTIGATION

1.0 HELICOPTER MAINTENANCE PROGRAM

1.1 HELICOPTER INFORMATION

The accident helicopter was an Airbus Helicopters Deutschland GmbH MBB-BK 117 C-2, serial number (SN) 9474, manufactured in 2011, powered by two Safran Helicopter Engines (SafranHE) turboshaft engines. The helicopter was registered to Duke University Health System Inc. and operated by AMC. The registration on file with the Federal Aviation Administration (FAA) for the date of issue is December 6, 2011. The helicopter was placed on AMC operating certificate on May 29, 2011 and had 20:31 total flight hours and 56 landings at that time. The helicopter had 2,711:02 total flight hours with 7,113 total landings as of September 6, 2017, the most recent available logbook entry (logbook sheet No. 1373077). The logbook was on-board the aircraft and consumed by post-crash fire; therefore, exact times and cycles are unknown. **TABLE 1** provides pertinent engine information and the accumulated operating hours and cycles as of the last logbook entry.

TABLE 1: ENGINE INSTALLATION INFORMATION

	NO. 1 ENGINE	NO. 2 ENGINE
MANUFACTURER/MODEL	SafranHE Arriel 1 E2	SafranHE Arriel 1 E2
PART NUMBER (PN)	0292005460	0292005460
MANUFACTURE DATE	December 1, 2010	December 8, 2010
DATE INSTALLED	June 17, 2011	June 17, 2011
ENGINE SERIAL NUMBER (ESN)	47292	47346
TIME SINCE OVERHAUL (TSO) (ENGINE HOURS)	N/A	N/A
CYCLES SINCE OVERHAUL (CSO) (ENGINE CYCLES)	N/A	N/A
ENGINE TIME SINCE NEW (TSN) HOURS	2,714:15	2,714:15
ENGINE CYCLES SINCE NEW (CSN)	7,119	7,119
TOTAL TIME OF HELICOPTER AT ENGINE INSTALLATION (HOURS)	New at factory	New at factory

[1] According to the FAA Type Certificate Data Sheet (TCDS) No. H13UE, Eurocopter Deutschland GmbH changed name to Airbus Helicopter Deutschland GmbH on January 7, 2014. The accident helicopter was manufactured in 2011 by Eurocopter Deutschland GMBH. For the remainder of this report, the helicopter manufacture will be referred to as Airbus Helicopters and the helicopter model will be referred to as Airbus Helicopters MBB-BK 117 C-2 or just MBB-BK 117 C-2.

SafranHE, formerly known as Turbomeca, will, for consistency, be referred to as Turbomeca for the remainder of the report when referring to reference material since most, if not all, the guidance material, maintenance manual material, maintenance records, service bulletins (SB), technical modifications, etc. are affixed with the Turbomeca name and or insignia. SafranHE will be used only in reference to the company name and where it does not appear otherwise on documents as Turbomeca.

All directional references to front and rear; right and left; top and bottom; and clockwise and counterclockwise are made aft looking forward (ALF) as is the convention unless otherwise stated. All numbering is in the circumferential direction starting with the No. 1 position at the 12:00 o'clock position or immediately clockwise from the 12:00 o'clock position and progressing sequentially clockwise ALF unless otherwise stated. The direction of rotation of the engine's gas generator is clockwise ALF, the engine's power turbine is counterclockwise ALF, and the helicopter main rotor counterclockwise ALF.

1.2 Air Carrier Certificate

On March 1, 1992, the FAA, Northwest Mountain Region Flight Standards District Office (FSDO) issued AMC of 7211 S Peoria St, Englewood, Colorado. Air Carrier Certificate Number QMLA253U (**Attachment 1**).

1.3 Operations Specifications[2]

AMC was authorized to conduct 14 *CFR* Part 135 On Demand Operations under of the code of Federal Aviation Regulations (FAR), which includes the standards, terms, conditions, and limitations contained in the FAA approved Operations Specifications (OpsSpecs), Parts D and E.

a) Per Section D073 of the OpsSpecs, AMC was authorized to use an Approved Aircraft Inspection Program (AAIP), document number MBB-BK 117 C-2 dated September 9, 2015, revision 010 in order to maintain the Airbus Helicopters Model MBB-BK 117 C-2.

b) Per Section D085 of the OpsSpecs, AMC has 11 Agusta A-A109-E, 13 Agusta A-A119-A119, 10 AW119-MKII, 33 Airbus Helicopters AS-350-B2, 55 AS350-B3, 1 AS-365-N2, 3 AS-365-N3, 3 Beriev BE-200-B206, 72 Bell BHT-407-407, 1 BHT-412-412, 2 BHT-412-EP, 5 BHT-429-429, 2 BHT-430-430, 37 Airbus Helicopters EC-130-B4, 11 EC-130-T2, 15 EC-130-T2+, 2 ECD-EC135-P1, 15 ECD-EC135-P2, 32 ECD-EC135-P2+, 1 ECD-EC135-T1, 13 ECD-EC135-T2, 2 Airbus Helicopters MBB-BK 117 A-3, 3 MBB-BK 117 A-4, 5 MBB-BK 117 B-1, 9 MBB-BK 117 B-2, 2 MBB-BK 117 C-1, 22 MBB-BK 117 C-2, 3 McDonald Douglas MD-900, 3 Pilatus PC-12-47, 1 PC-12-47E and 1 Airbus Helicopter SA-365-N1 listed. AMC had at the time of the accident a total of 388 aircraft on their OpsSpec.

c) Per Section D093 of the OpsSpecs, AMC was authorized to conduct Helicopter Night Vision Goggle Operations (HNVGO) under the limitations and provisions of 14 *CFR* Part 135 and paragraph A050 of the OpsSpecs using aircraft listed in table 1 of the OpsSpecs. The Night Vision Imaging System (NVIS) includes the approved installed equipment and the Night Vision Goggles

2 Operations Specifications contains the authorizations, limitations, and certain procedures under which each kind of operation, if applicable, is to be conducted by the certificate holder.

(NVG). The NVIS and NVG's used to conduct HNVGO shall be maintained in accordance with the maintenance documents listed in Section DO093, table 1.

d) Per Section D095 of the OpsSpecs, AMC was authorized to use an FAA-approved Minimum Equipment List (MEL) provided the conditions and limitations are met. The certificate holder is authorized to use an FAA-approved MEL for the aircraft listed in Section D095 which includes the Airbus Helicopters MBB-BK 117 C-2 model helicopter.

e) Per Section D102 of the OpsSpecs, the certificate holder was authorized to use the following rotorcraft type identified below in its 14 *CFR* Part 135 nine seats or less operations provided these rotorcrafts have met the additional maintenance requirements of Section 135.421. Each installed engine, to include turbosuperchargers, appurtenances, and accessories for its functioning shall be maintained in accordance with the maintenance documents listed. The engine shall be overhauled on or before the time-in-service interval shown. MBB-BK 117 C-2 helicopters, Turbomeca Arriel 1 E2 turboshaft engines maintained per Maintenance Manual (MM) No. X 292 M3 452 2. The following limits apply to the various engine modules based on hardware incorporation (see Section 2.1.2 ENGINE DESCRIPTION for description of the engine modules): 1) Module M01 – On Condition, 2) Module M02 Basic Standard – 6,000 Hours, 3) Module M02 Post Turbomeca TU 275 – 7,200 Hours, 4) Module M03 Basic Standard Configuration – 2,500 Hours, 5) Module M03 Post TU 195 and 202 – 3,000 hours, 6) Module M03 Post TU 195, 202, 244, 277, and 278 – 3,600 Hours, 7) Module M04 – 7,200 Hours, and 8) Module M05 – 3,600 Hours. A 15 year limit applies to all modules. Each installed main and tail rotor shall be maintained in accordance with the manufacturer's maintenance documents listed. Rotor Main and Auxiliary Maintenance Document – Airbus Helicopters Aircraft Maintenance Manual MBB-BK 117 C-2 (See **ATTACHMENT 2** for all TUs incorporated).

f) Per Section E096 of the OpsSpecs, AMC was authorized to use individual aircraft weights outlined in the certificate holders' empty weight and balance control program for the aircraft listed in table 1. According to the document, the MBB-BK 117 C-2 helicopters were to be individually weighed every 36 months, General Operations Manual (GOM) Section 2, Weight and Balance Control.

1.4 AIRCRAFT TYPE CERTIFICATE DATA SHEET

The Type Certificate Data Sheet (TCDS), prescribes conditions and limitations under which the product for which the Type Certificate (TC) was issued meets the airworthiness requirements of the applicable *CFRs*. According to the FAA TCDS H13EU, Airbus Helicopters Deutschland GmbH is the holder of the TC for model MBB-BK 117 C-2 helicopter.

1.5 APPROVED AIRCRAFT INSPECTION PROGRAM (AAIP)

The accident helicopter was owned and/or operated by AMC are maintained in accordance with their AAIP. The AAIP is based on the manufacturer's recommended inspection program. The AAIP applicable sections for the MBB-BK 117 C-2 are as follows:

- Section A of the AAIP applies to MBB-BK 117 C-2 aircraft. There are 16 Section A airframe zonal inspections (Zones 1 – 16) completed in sequential order within 50 hours of the last zonal inspection. In addition, there are standalone inspections due every 30 hours, 200 hours, 800 hour/12 month, two 800 hour/36 month, 1200 hours, two 1600 hours, 2400 hours, 3200 hours, and a 60 day inspection.

- Section B of the AAIP applies to SafranHE Arriel 1 E2 engines installed in MBB-BK 117 C-2 aircraft. There is a 30 hour inspection along with 12 Section B zonal inspections (Zones 1 - 12) completed in sequential order within 50 hours of the last engine zonal inspection. In addition, there are standalone engine inspections due every 300 hour/12 month, 1200 hour, 30 day compressor wash, and every 12 months a compressor wash.
- Section C of the AAIP apples to MBB-BK 117 C-2 aircraft in their FAA approved altered state. These tasks are individually tracked. There is a 12 month Avionics Inspection, 24 month Avionics Inspection, 24 month Air Traffic Control (ATC) Transponder System, 24 month Altimeter System, 50 hour inspection of installed equipment, two individual 100 hour inspection of installed equipment, a 100 hour/90 day inspection of installed equipment, three 100 hour/12 month inspections of installed equipment, a 150 hour/12 month inspection of installed equipment, a 200 hour/90 day inspection of installed equipment, a 200 hour/90 day inspection (initial inspection at 600 hours/12 months battery time since new) of installed equipment, a 300 hour inspection of installed equipment, a 300 hour/180 day inspection of installed equipment, a 300 hour/12 month inspection of installed equipment, a 400 hour/12 month inspection of installed equipment, a 600 hour/12 month inspection of installed equipment, 600 hour/24 month inspection of installed equipment, 1200 hour/24 month inspection of installed equipment, 30 day inspection of installed equipment, 90-day inspection of installed equipment, 30 day liquid oxygen (LOX) inspection, 180 day inspection of installed equipment, 180 day LOX Inspection, 180 day inspection of X-Back Molle Life Vest, 180 day inspection of all Passenger Life Vest, 180 day inspection of Infant Life Vest, two 12 month inspection of installed equipment, a 100 hour Nickel Cadmium (NiCad) battery inspection, a 30 day NiCad battery inspection, a 150 and 300 hour NiCad battery top charge, a 300 hour NiCad battery recondition, and a 12 month NiCad battery recondition.
- Attachment D of the AAIP contains additional independent inspection items and maintenance tasks (i.e. lubrications or unique requirements) applicable to the airframe, engines, components, or items installed under FAA Form 337.

Documents included in the AAIP as reference material include:

- Title 14, *Code of Federal Regulations* (14 CFR).
- Airworthiness Directives.
- Type Certificate Data Sheets for Aircraft, Engines and Propellers.
- Air Methods General Operations Manual
- Air Methods General Maintenance Manual
- Air Methods Field Mechanic Procedures Manual.
- Air Methods Aircraft Status Report.
- Aircraft Logbooks.
- Advisory Circular (AC) 43-4A, Corrosion Control for Aircraft.
- MBB-BK 117 C-2:
    - Maintenance Manual.
    - Maintenance Program.
    - Mechanical Repair Manual.
    - Structural Repair Manual.
    - Wiring Diagrams.
    - Service Bulletins.

- SafranHE Arriel 1 E2:
    - Maintenance Manual.
    - Service Bulletins.
- FAA Form 337s documenting major alterations to MBB-BK 117 C-2 aircraft operated by AMC.
- Continued Airworthiness instructions issued by Supplemental Type Certificates (STC) holders.
- National Fire Protection Association, NFPA 10.
- Concord Battery Corporation Battery Products Instruction Manual.
- Additional references, as required.

The following is a listing of recent zonal inspections accomplished on the accident helicopter, N146DU. Zone A items are for the airframe and Zone B items are for the engine.

TABLE 2: MAINTENANCE CHECKS

CHECK	DATE	TOTAL TIME	TOTAL CYCLES
A0301 Zone 1 Inspection	3/2/2017	2,406:18	6,363
A0302 Zone 2 Inspection	4/19/2017	2,444:08	6,456
A0303 Zone 3 Inspection	5/05/2017	2,479:57	6,537
A0304 Zone 4 Inspection	5/19/2017	2,513:29	6,611
A0305 Zone 5 Inspection	6/13/2017	2,552:59	6,725
A0306 Zone 6 Inspection	7/10/2017	2,592:26	6,845
A0307 Zone 7 Inspection	7/26/2017	2,635:16	6,946
A0308 Zone 8 Inspection	8/15/2017	2,673:35	7,033
A0309 Zone 9 Inspection	8/31/2017	2,710:23	7,109
A0310 Zone 10 Inspection	9/19/2016	2,137:41	5,725
A0311 Zone 11 Inspection	10/12/2016	2,178:03	5,815
A0312 Zone 12 Inspection	11/1/2016	2,211:19	5,884
A0313 Zone 13 Inspection	11/23/2016	2,255:31	5,977
A0314 Zone 14 Inspection	12/20/2016	2,300:15	6,077
A0315 Zone 15 Inspection	1/12/2017	2,341:03	6,183
A0316 Zone 16 Inspection	2/9/2017	2,379:04	6,291*
B0230 No. 1 Engine 30 Hour Inspection	8/25/2017	2,696:29	
B0230 No. 2 Engine 30 Hour Inspection	8/25/2017	2,696:29	
B0301 No. 1 Engine Zone 1 Inspection	3/25/2017	2,406:18	
B0301 No. 2 Engine Zone 1 Inspection	3/26/2017	2,406:18	
B0302 No. 1 Engine Zone 2 Inspection	4/19/2017	2,444:08	
B0302 No. 2 Engine Zone 2 Inspection	4/19/2017	2,444:08	
B0303 No. 1 Engine Zone 3 Inspection	5/5/2017	2479:57	
B0303 No. 2 Engine Zone 3 Inspection	5/5/2017	2,479:57	
B0304 No. 1 Engine Zone 4 Inspection	5/19/2017	2,573:29	
B0304 No. 2 Engine Zone 4 Inspection	5/19/2017	2,573:29	
B0305 No. 1 Engine Zone 5 Inspection	6/13/2017	2,552:59	

Table 2: Maintenance Checks

CHECK	DATE	TOTAL TIME	TOTAL CYCLES
B0305 No. 2 Engine Zone 5 Inspection	6/13/2017	2,552:59	
B0306 No. 1 Engine Zone 6 Inspection	7/10/2017	2,592:26	
B0306 No. 2 Engine Zone 6 Inspection	7/10/2017	2,592:26	
B0307 No. 1 Engine Zone 7 Inspection	7/26/2017	2,635:16	
B0307 No. 2 Engine Zone 7 Inspection	7/26/2017	2,635:16	
B0308 No. 1 Engine Zone 8 Inspection	8/15/2017	2,673:35	
B0308 No. 2 Engine Zone 8 Inspection	8/15/2017	2,673:35	
B0309 No. 1 Engine Zone 9 Inspection	8/31/2017	2,710:23	
B0309 No. 2 Engine Zone 9 Inspection	8/31/2017	2,710:23	
B0310 No. 1 Engine Zone 10 Inspection	12/19/2016	2,300:14	
B0310 No. 2 Engine Zone 10 Inspection	12/19/2016	2,300:14	
B0311 No. 1 Engine Zone 11 Inspection	1/12/2017	2,341:03	
B0311 No. 2 Engine Zone 11 Inspection	1/12/2017	2,341:03	
B0312 No. 1 Engine Zone 12 Inspection	2/9/2017	2,379:04	
B0312 No. 2 Engine Zone 12 Inspection	2/9/2017	2379:04	
A1820 800 Hour/12 Month Inspection	3/9/2017	2,406:18	6,363
A1860 800 Hour/36 Month Inspection	3/1/2017	2,406:18	6,363
A1861 800 Hour/36 Month Inspection	8/4/2016	2,043:43	5,488
A2210 1200 Hour Inspection	3/2/2017	2,406:18	6,363
A2410 1600 Hour Inspection	12/15/2015	1,718:58	4,686
A2411 1600 Hour Inspection	12/18/2015	1,718:58	4,686
A3110 2400 Hour Main Transmission	3/30/2017	2,406:18	6,363
A5170 60 Day Inspection	8/15/2017	2,673:35	7,032
B1040 No. 1 Engine 300 Hour/12 Month	7/26/2017	2,635:16	
B1040 No. 2 Engine 300 Hour/12 Month	7/26/2017	2,635:16	
B2210 No. 1 Engine 2200 Hour	3/25/2017	2,406:18	
B2210 No. 2 Engine 2200 Hour	3/25/2017	2,406:18	
D3114 No.1 Engine 2400 Hour Inspect Engine Mounts (Engine Removed)	3/6/2017	2,406:18	
D3114 No.2 Engine 2400 Hour Inspect Engine Mounts (Engine Removed)	3/25/2017	2,406:18	
B5099 No. 1 Engine 30 Day Compressor Wash	9/6/2017	2,710:37	7,112
B5099 No. 2 Engine 30 Day Compressor Wash	9/6/2017	2,710:37	7,112

* Estimated, logbook did not include cycles

- Engine Zone B 0304 engine inspection, item 3.2, is the inspection of the rear bearing for clogging, reference TASK 72-43-10-280-801-A01. Effectivity: Pre and post TU 274, TU 281, TU 283, and TU 284.

- Engine Zone B 0310 engine inspection, item 5.1, is the inspection and check of the oil scavenge line of the gas generator rear bearing, reference TASK 79-38-00-210-801-A01. Effectivity: Pre-and post-modifications TU 274, TU 281, TU 283, and TU 284.

1.6 Supplemental Type Certificates (STC)[3]

Supplemental Type Certificates (STCs) and major alterations supplied by AMC and on file with the FAA were reviewed. There was a total of 30 major alterations and/or STC's on file with the FAA. All major alterations were airframe related with none being related to the engines.

1.7 Major Repairs

There were two major repairs on file with the FAA that were reviewed. The major repairs were airframe related and did not affect the engines.

1.8 Airworthiness Directive (AD)[4]

AMC provided an AD summary (airplane, powerplants and appliances) for review. There was a total of 20 AD's that affected the airframe or engines. All AD's were either complied with, scheduled for compliance, or recurring requirements being tracked. The engine AD's reviewed were AD 2016-01-14 N2 Control Arm, AD 2013-08-22 Engine Tachometer, AD 2012-27-02 Vibration Test Requirement, AD 2017-15-07 Fuel Drain Valve, and AD 2012-23-12 Fuel Control, Union. AD's are tracked by either airframe or engine serial numbers, flight hours, flight cycles (landings) or calendar, or combination of as required. The status report includes compliance status, last performed, interval (if applicable), and next due. No discrepancies were found during the review.

1.9 Service Difficulty Reports (SDR)[5]

According to the FAA SDR Database, there were three SDRs submitted on the accident helicopter. None of the SDRs were related to either of the accident engines.

1.10 Minimum Equipment List (MEL)[6]

AMC was authorized to use an approved MEL on its aircraft per its OpsSpecs. A six-month review of MEL items showed two items that were open and cleared during the time period reviewed with the most recent being closed on August 2, 2017. At the time of the accident, there were no open MEL items.

[3] The FAA issues STC, which authorize a major change or alteration to an aircraft, engine or component that has been built under an approved Type Certificate.
[4] An AD is a regulatory notice sent out by the FAA informing the operator of an action that must be taken for the aircraft to maintain its airworthiness status.
[5] An SDR is a report of the occurrence or detection of each failure, malfunctions, or defects as required by 14 CFR Part 135.415.
[6] The FAA approved MEL contains a list of equipment and instruments that may be inoperative on a specific aircraft for continuing flight beyond a terminal point.

1.11 Aircraft Flight Logs

Aircraft Flight Logbooks and Maintenance Worksheets were reviewed from April 3, 2017 thru September 6, 2017. The subsequent aircraft flight logbooks were in the aircraft at the time of the accident and could not be reviewed. The review focused on the engines and engine indicating systems including the chip detector related MASTER caution light illuminations; no log entries for this type of discrepancies were found. The following work was noted (Table 3):

Table 3: Aircraft Flight Logbooks and Maintenance Worksheets Entries

LOGBOOK NO.	DATE	TOTAL TIME	ITEM	ACTION
1373077	9/6/2017	2,710:37	30 Day Compressor Wash	Engine Nos. 1 and 2 Compressor Wash Completed per AAIP B5099
1373075	9/1/2017	2,710:23	Enter Data from Power Assurance Check into Logbook and Trend Record	Engine Nos. 1 and 2 - Power Assurance Data Entered per AAIP D0330
1373059	8/15/2017	2673:35	Leak Test of Deceleration Control Unit -Check of FCU Characteristics	Engine Nos. 1 and 2 – Zone 8 Inspection Completed
1373053	8/9/2017	2,665:37	100 Hour take Oil Sample for Spectrometric Analysis	Engine Nos. 1 and 2 - Oil Sample Taken per AAIP D0520
1373033	7/20/2017	2,623:40	Engines 1 and 2 Require Oil Service	Serviced Engine Nos. 1 and No. 2 with ½ quart each Mobil Jet II
1373023	7/10/2017	2,592:26	300 Hour/12 Month Drain & Replace Engine Oil	Engine Nos. 1 and 2 - Oil Replaced per AAIP D1040
13730106	7/3/2017	2,587:48	100 Hour take Oil Sample for Spectrometric Analysis	Engine Nos. 1 and 2 - Oil Sample Taken per AAIP D0520
1373002	6/19/2017	2,562:45	Oil Cooler Shaft on #1 Side Leaking	Replace O-ring in accordance with (IAW) Airplane Maintenance Manual (AMM) TASK 79-23-00, 8-3. Checked Good
1372624	5/22/2017	2,520:43	10 Minutes into Flight Crew Noticed Electrical Burning Smell in Cabin. Turned aircraft (A/C) off then okay.	Troubleshot the A/C system and electrical system, no issues found IAW MBB-BK 117 C-2 MTC 20-80-20-445 – No additional writes-up were found that addressed the smell or indicated that the odor remained
1372612	5/10/2017	2,497:28	100 Hour take Oil Sample for Spectrometric Analysis	Engine Nos. 1 and 2 - Oil Sample Taken per AAIP D 0520
1456182	4/11/2017	2,423:05	Engines 1 and 2 Require Oil Service	Serviced Engines No. 1 and No. 2 with ½ quart each Mobil Jet II
1456173	4/1/2017	2,406:18	Compressor wash due	Complied with 00-7100-EO-1651 compressor wash performed on engine Nos. 1 and No. 2
1456173	3/30/2017	2,406:18	100 Hour take Oil Sample for Spectrometric Analysis	Engine Nos. 1 and 2 Oil Sample Taken per AAIP D0520
1456173	3/29/2017	2,406:18	Engine 1 and 2, Initial and Repetitive check of 2nd stage turbine blades due	Complied with 00-7250-EO-171 and SB 292 72 0264 version E dated 1/2007 Engine Nos. 1 and 2
1456173	3/1/2017	2,406:18	Enter Data from Power Assurance Check into Logbook and Trend Record	Engine Nos. 1 and 2 - Power Assurance Data Entered per AAIP D0330
1456173	3/1/2017	2,406:18	1200 Hour Engine Inspection Due	Engine Nos. 1 and 2 - 1200 hour inspection completed IAW AAIP B 2210
1456173	2/22/2017 to	2,406:18	Aircraft Major Maintenance	Engines Nos. 1 and 2 Removed from Airframe

Table 3: Aircraft Flight Logbooks and Maintenance Worksheets Entries				
	3/30/2017			
1456159	2/9/2017	2,379:04	Enter Data from Power Assurance Check into Logbook and Trend Record	Engine Nos. 1 and 2 - Power Assurance Data Entered per AAIP D0330
1425531	1/12/2017	2,341:03	Number two engine start drain valve leaking	Replace start drain valve IAW 73-16-11-900-801-A01
1425531	1/12/2017	2,341:03	300 Hour / 12 Month Engine Inspection	Engine Nos. 1 and 2 - 300 Hour / 12 Month Inspection completed IAW AAIP B1040
1425531	1/12/2017	2,341:03	300 Hour/12 Month Drain & Replace Engine Oil	Engine Nos. 1 and 2 - Oil Replaced per AAIP D1040
1425531	1/12/2017	2,341:03	100 Hour take Oil Sample for Spectrometric Analysis	Engine Nos. 1 and 2 - Oil Sample Taken per AAIP D0520

1.12 Weight and Balance Summary

Per the AMC OpsSpecs, the aircraft was to be weighed every thirty-six (36) calendar months. The last actual weight and balance for N146DU was accomplished on March 17, 2015 in Smithfield, NC (Johnston County Airport). **Table 4** provides the last weight and balance of the accident helicopter.

Table 4: Accident Helicopter Weight and Balance	
Basic Empty Weight:	2,452.96 kilograms (kg)
Arm:	4,613.34 millimeters (mm)
Horizontal Moment:	11,316,350.00 kg-mm

Note - Empty weight includes 9.30 kilograms for unusable fuel.

1.13 Time Limit Components

Time Limit Component status for the helicopter and the two installed powerplants were reviewed. The review included time limited ratable components installed on N146DU and both engines. Components are tracked by the PN and SN. Engine components listed in the logbooks were cross checked with AMC tracking system. No discrepancies were noted during the review.

1.14 Manuals

AMC used the following manuals to maintain the airworthiness of its fleet of aircraft:

- General Operations Manual (GOM) - The GOM contains policies and procedures governing the operation of the flight department of AMC. The manual provides guidelines enabling all company personnel to carry out their assigned duties and responsibilities in accordance with company policies and FAA regulations.

- General Maintenance Manual (GMM) - The GMM contain procedures and instructions that maintenance personnel use to conduct maintenance on AMC fleet of aircraft, engines, and components. Each employee is responsible to ensure the version is current. A current version is posted on the AMC Internet Flightdeck.

- Approved Aircraft Inspection Program - AAIP, document number MBB-BK 117 C-2 AAIP, dated July 8, 2017, revision (1) is used to maintain the MBB-BK 117 C-2 model helicopters. The AAIP includes three sections; Section A applies to the aircraft, Section B applies to the engines installed, and Section C applies to the aircraft in their FAA approved altered state. In addition, Attachment D of the AAIP contains independent inspections applicable to the airframe, engines or items installed under FAA form 337.

- Minimum Equipment List (MEL) - The MEL provides information pertaining to the dispatch of aircraft with inoperative system(s) and references maintenance procedures relating to inoperative MEL items.

- Manufacture Supplied Manuals - Aircraft/Engine Maintenance Manuals, Structural Repair Manuals, Overhaul Manuals, Wiring Manuals, Illustrated Parts Catalog, SBs, EMs, and other FAA approved or accepted manuals to perform maintenance.

1.15 METHOD OF RECORD KEEPING

Per FAR Parts 43, 91 and 135, AMC maintains records with the use of Aircraft Logbooks, the AAIP inspection checklists which includes the inspection program and the use of Maintenance Work Sheets form 5436 as an extension of the aircraft logbook to record maintenance. Aircraft logbook pages, AAIP inspection checklists, maintenance work sheets (form 5436 and serviceability tags (FAA form 8130s, Parts Tags, etc.) are sent to the AMC Maintenance Record's for review and archiving. AMC is authorized to utilize an electronic record keeping system, Air Vault (OpsSpecs AO25 electronic record keeping systems).

AMC also uses a computerized electronic tracking program to assist in tracking:

- Scheduled maintenance.
- Component/Equipment.
- Airworthiness Directives.
- Service Bulletins.
- Life Limited Components.
- Aircraft Status Report Items.

2.0 POWERPLANTS

2.1 GENERAL POWERPLANT AND ENGINE SYSTEM DESCRIPTION

2.1.1 Engine Description

The Arriel 1 E2 turboshaft engine is a twin-spool free turbine engine with a single-stage axial compressor and a single-stage centrifugal compressor that drives a two-stage gas generator turbine, an annular combustion chamber, and a single-stage power turbine (free turbine) that drives the transmission shaft through a reduction gearbox (**FIGURE 1**). According to the FAA's TCDS E19EU, revision 16, dated February 7, 2017, the Arriel 1 E2 was issued a TC on June 26, 1992 and has the following power ratings[7]: 1) 708 shaft horsepower (SHP) for 2½ minutes one engine inoperative (OEI), 2) 708 SHP for 30 minutes OEI, 3) 708 SHP for continuous OEI operation, 4) 708 SHP for takeoff, and 5) 692 SHP maximum continuous. The maximum gas generator speed (N1 speed or Ng speed) is 53,509 revolutions per minute (rpm) and the maximum power shaft speed (also referred to as the transmission shaft or N2 speed) is 6,480 rpm; 100% transmission speed is 6,000 rpm.

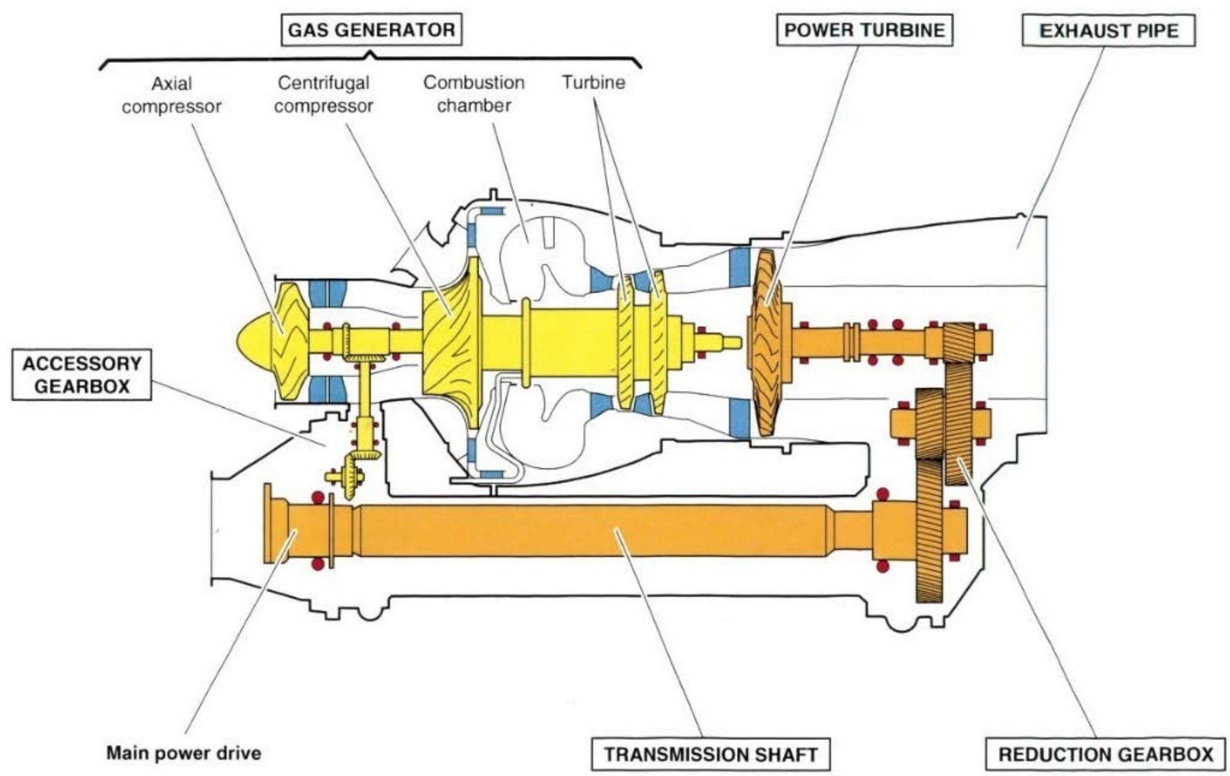

FIGURE 1: ENGINE CROSS-SECTION

FIGURE COURTESY OF SAFRANHE

[7] Engine power rating are based on calibration test rig under the following conditions: 1) static sea level conditions, no bleed or accessory power extraction, 2) 6,000 rpm output shaft drive speed, and 3) heating value of fuel = 18,566 British Thermal Unit (BTU)/pound.

The Arriel 1 E2 is a modular turboshaft engine where each sub-assembly is an independent unit that can be removed, inspected, or replaced on-site without complex tooling, without fully disassembling the engine, or the need to send the engine to a maintenance facility to complete an overhaul. The engine has five modules and each with its own identification plate. The engine identification plate is fitted to the right side of the module M01 protection tube. The modules (FIGURE 2) are as follows:

Module M01: Transmission Shaft and Accessory Gearbox (AGB)
Module M02: Axial Compressor
Module M03: Gas Generator – High Pressure Section
Module M04: Power Turbine
Module M05: Reduction Gearbox (RGB)

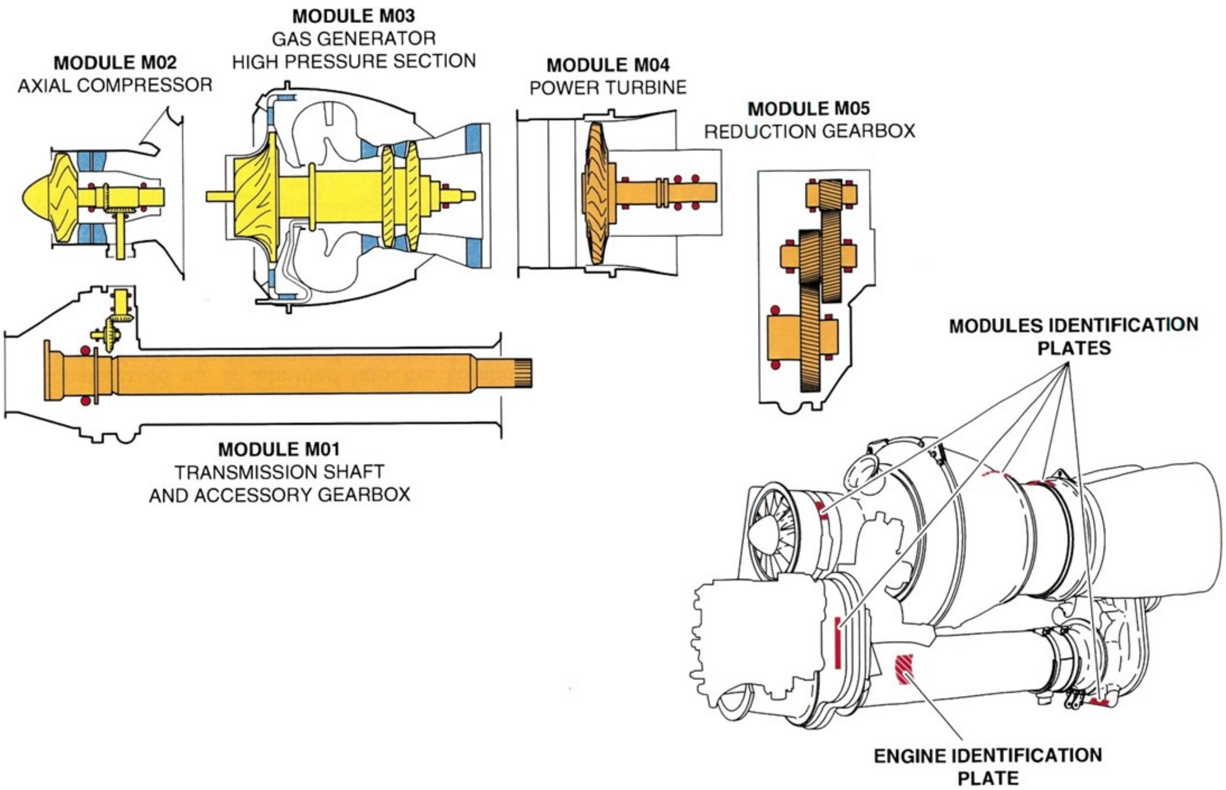

FIGURE 2: ENGINE MODULES

FIGURE COURTESY OF SAFRANHE

2.1.2 Engine Module M03: Gas Generator Description

Module M03 (FIGURE 3) is comprised of the centrifugal compressor, the combustion chamber, and the gas generator turbine. A center tie-bolt connects and secures the rotating components of the gas generator; the centrifugal compressor wheel at the front and the two gas generator turbine wheels in the back via a stub shaft that is coupled to the second stage turbine wheel by a curvic-coupling. The stub shaft is supported by a roller bearing; this bearing will be commonly referred to as the rear bearing for the remainder of this report. Rotating labyrinth seals provide sealing of the bearing compartment.

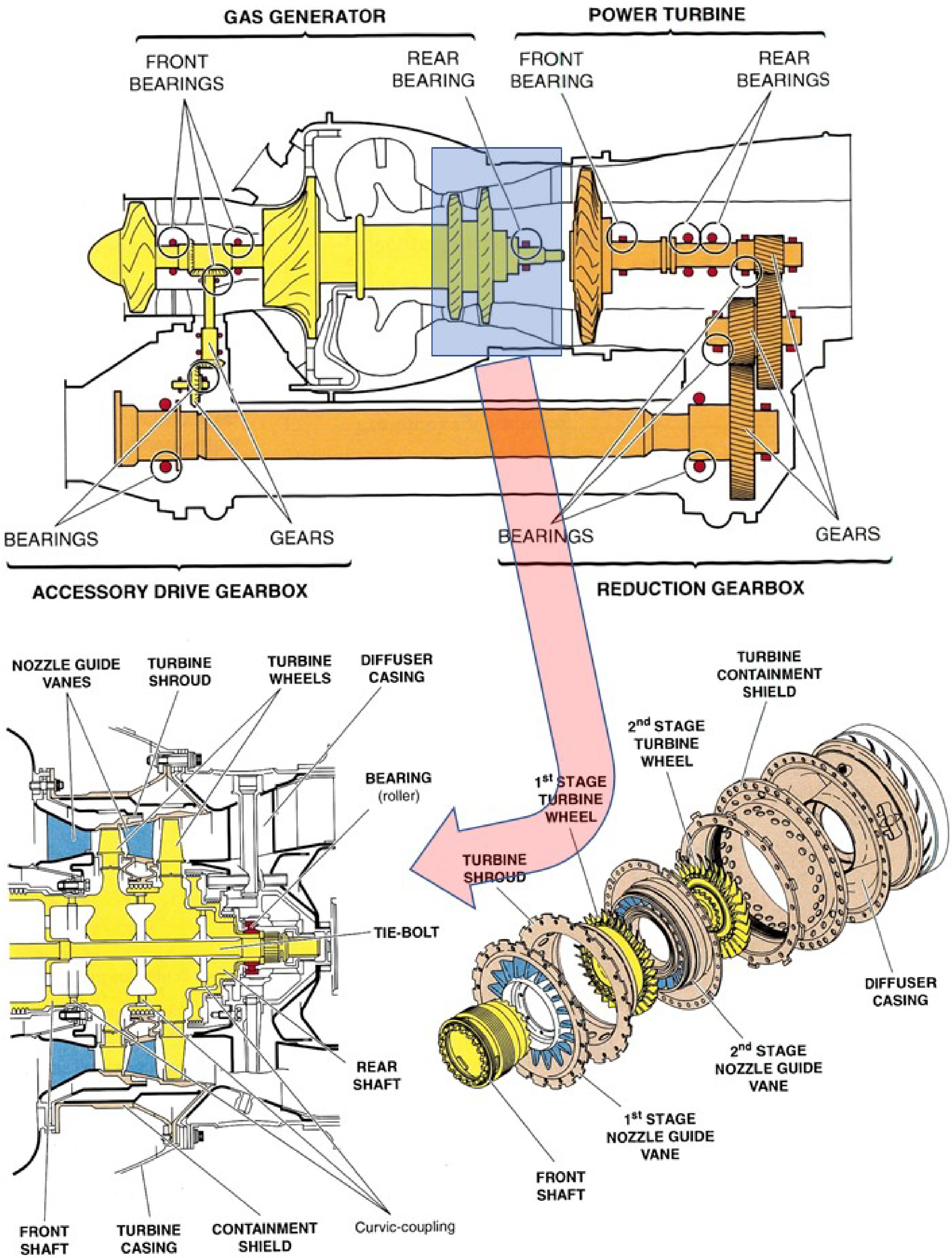

Figure 3: Gas Generator (M03) Cross-Section and Exploded View

Figure Courtesy of SafranHE

2.1.3 Engine Oil System Description

The engine oil pump draws oil from the oil tank and delivers it through an oil filter to the various bearing compartments via dedicated oil jets. For the Arriel 1 E2, the oil filter pre-blockage indicator was replaced with a pre-blockage pressure switch. The pre-blockage signal is sent to the cockpit when the differential pressure (ΔP) upstream and downstream of the oil filter element is greater than 21.7 pounds per square inch differential (psid). After the bearings are lubricated, the oil falls to the bottom of the bearing compartment (sump) by gravity and scavenge pumps return the oil to the tank. The oil pump, which is mounted on the rear face of the accessory gearbox, is comprised of a pack of pumps within a single unit. Within this single unit is the pressure pump that provides oil to the bearing compartments and the three scavenge pumps that draw oil back to the oil tank from the following bearing compartments (sumps): 1) AGB, 2) the gas generator rear bearing, and 3) RGB (FIGURE 4). Scavenge strainers are used to protect the scavenge pumps against any particles which may be suspended in the oil that could damage the pump.

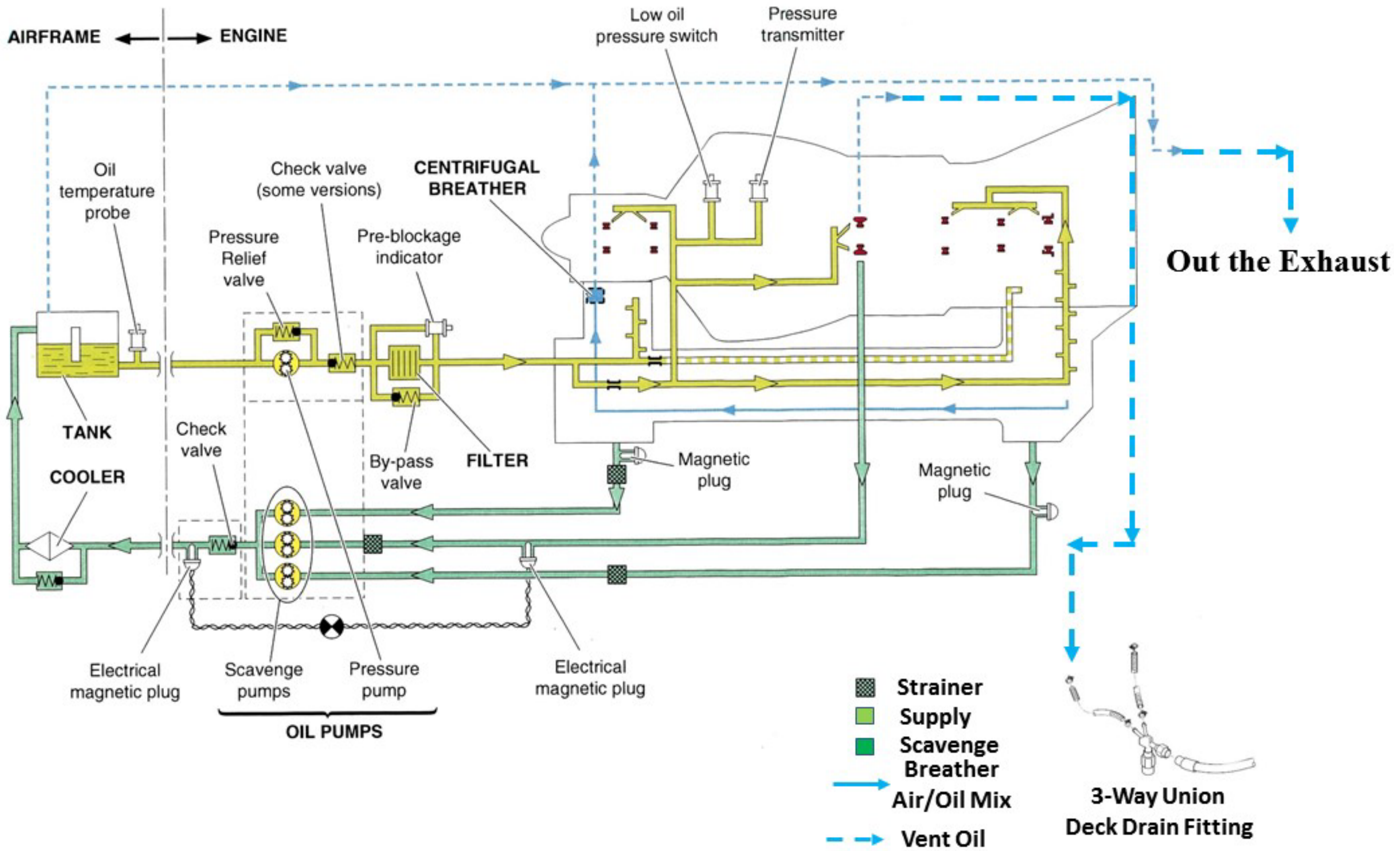

FIGURE 4: OIL SYSTEM SCHEMATIC

FIGURE COURTESY OF SAFRANHE

The ARRIEL 1 E2 is equipped with four magnetic chip detector plugs; two of which are electrical magnetic plugs (EMP) that provide cockpit indication of metal particles in the oil system (See FIGURE 4) and two which are mechanical magnetic plugs (MMP) that provide for rapid and frequent checking of the current condition of the engine but do not provide feedback to the cockpit on their condition. For the EMPs, one is located downstream of the scavenge pumps and the other is located upstream of the scavenge pump in the rear bearing oil scavenge line. For the MMPs, one is located in the RGB oil scavenge line and the other is located in the AGB oil scavenge line; thus, each oil scavenge line is equipped with an MMP, only the rear bearing oil scavenge line has the EMP. When sufficient metal material accumulates on one of the EMPs to trigger a signal, a signal is sent to the appropriate MASTER caution light on the warning panel and a caution indication appears on the Cautions and Advisory Display (CAD). The flashing yellow MASTER caution lights in the pilot's field of view leads the pilot's attention to the indication(s) on the CAD when a caution has been activated. The Master caution light always comes on in conjunction with any caution indication on the CAD. [8] The CAD will display the system effected, condition indication, and the emergency and malfunction procedure.

Turbomeca issued Service Bulletin (SB) No. 292 72 0163 Subject: INSTALLATION OF A CHIP DETECTOR WITH ELECTRIC WARNING ON THE REAR BEARING OIL RETURN - EMBODIMENT OF THE MODIFICATION TU 208 on April 4, 1992 to add an EMP with a caution panel warning on the gas generator rear bearing oil return system to inform the pilot of a deterioration in progress of the gas generator bearing. Metal particles are attached to magnetic plugs where they can be collected for future evaluation. In the case of the EMPs, if sufficient metal particles are collected, they can form a bridge across the electrical gap completing the circuit sending a signal to illuminate a light on the instrument panel. Along with the magnetic plugs, the engine is equipped with several strainer elements intended to trap large particles thus protecting the scavenge pumps from damage. Two strainers located in the accessory gearbox housing upstream of the reduction gearbox and accessory gearbox scavenge pumps and one is located upstream of the rear scavenge pump and is collocated with the rear bearing electrical magnetic plug.

The Arriel 1 E2 is also equipped with a secondary air system that positively pressurizes the bearing compartments to prevent oil from passing by the labyrinth seals and vents the extra pressure. The air/oil mist from the gas generator front bearings and from the power turbine front and rear bearings are returned to the accessory gearbox for processing by an air/oil centrifugal separator (centrifugal breather). The air/oil mist enters the air/oil separator and the centrifugal forces sling the oil into the bottom of the gearbox where it is collected and sent back to the oil tank. The de-oiled air is then vented through external lines and is expelled into the engine exhaust along with the vent air from the oil tank (See **FIGURE 4**). The air/oil mist from the rear bearing is not processed like the other bearing compartments or modules. Instead the air/oil mist is collected by the scavenge pump back to the oil tank. The excess air that ends up in the oil tank is then vented through a dedicated vent line going to the exhaust. The pressurized air in front of the rear bearing chamber is vented through dedicated oil vent lines (rigid steel line – engine component), to an oil vent line drain (a flexible elastomer line – airframe component), then to an steel oil drain fitting (airframe component) in the engine deck where it is finally vented overboard (**FIGURES 5** and **6** and **PHOTO 1**). This airframe drain fitting is often referred to as the deck fitting, or the 3-way union deck fitting and is where pressurized air/oil mist from the gas generator rear bearing, any oil that may leak from the rear bearing chamber of from the supply collector, and oil that may drip from the power output drive shaft seal join into this one fitting and is then vented overboard by a drain port on either the side of the helicopter. The air/oil mix from the generator rear bearing leaves the bearing compartment through a rigid steel oil vent duct, then through a rigid steel oil vent line, and finally through a flexible elastomeric oil vent line drain before it reaches the steel 3-way union deck fitting. Since the MBB-BK 117 C-2 helicopter is a dual engine airframe, there is one 3-way union deck fitting and airframe drain port for each engine (**FIGURE 7**).

[8] A caution indication on the CAD and the two yellow MASTER caution lights on the instrument panel indicates a malfunction or failure conditions that do not require immediate crew action but the possible need for future corrective action. Each caution (CAD-indication and MASTER caution light) must be acknowledged by the pilot (copilot) by pushing the RESET button on the cyclic stick grip or the SELECT key on the CAD. The Flight Manual (FM) then instructs the pilot to either shut-down the engine or to rotate the twist grip slowly to idle.

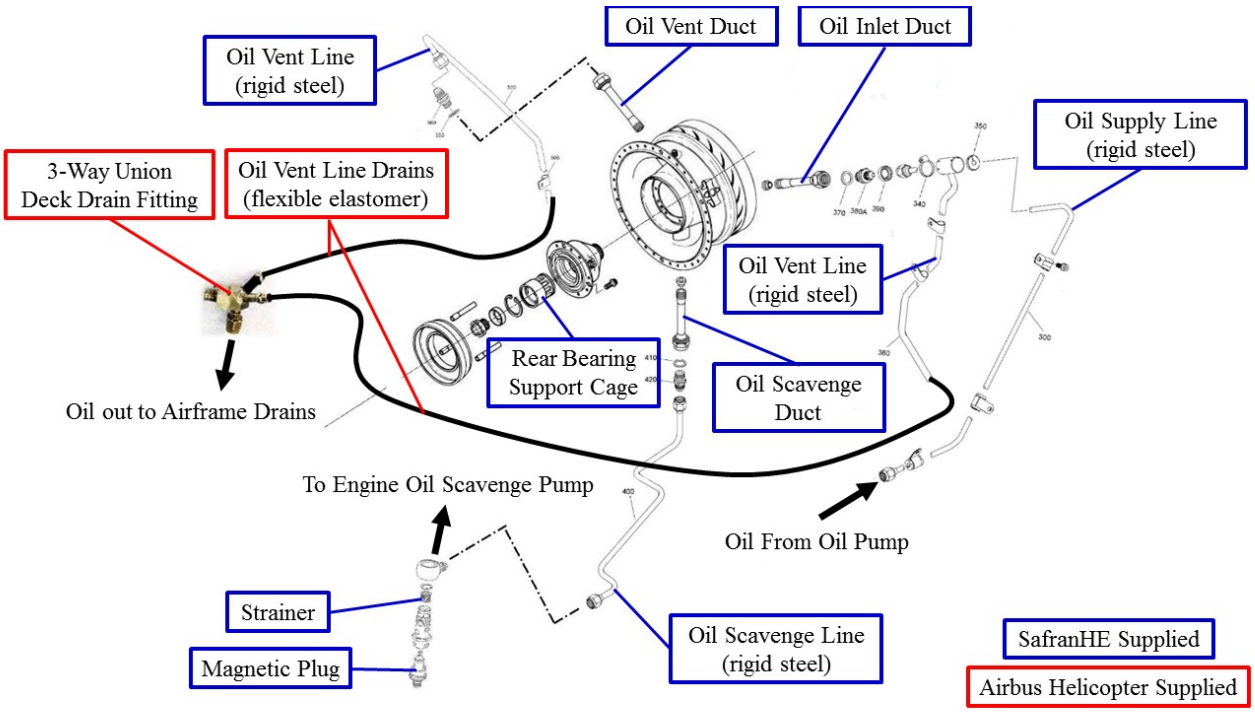

FIGURE 5: LINES AND DRAINS ATTACHED TO THE REAR BEARING AND 3-WAY UNION DECK DRAIN FITTING[9]

FIGURE COURTESY OF SAFRANHE

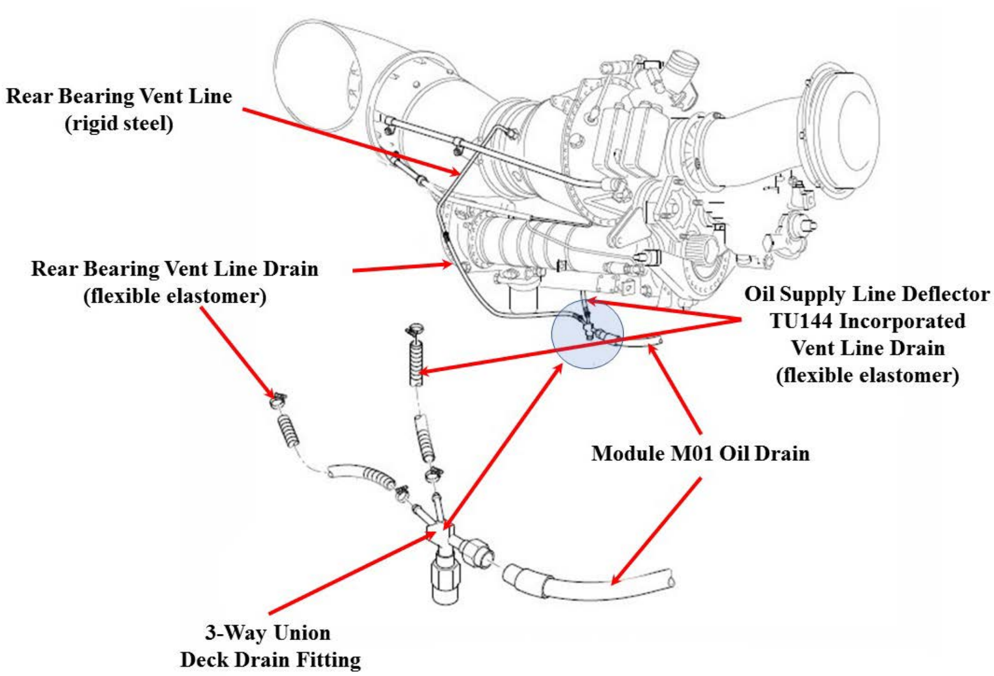

FIGURE 6: SCHEMATIC OF DRAIN LINES ATTACHED TO 3-WAY UNION DECK DRAIN FITTING

FIGURE COURTESY OF AIRBUS HELICOPTERS

[9] Review of the Turbomeca EMM instructions, service letters, and service bulletins have revealed that the term "line", "pipe" and "tube" has been used interchangeably. For consistence and to reduce confusion, the term "line" will be used throughout this report unless quoting directly from a document. Also, the term "return" and "scavenge" were found to be used interchangeably, only scavenge will be used throughout the report.

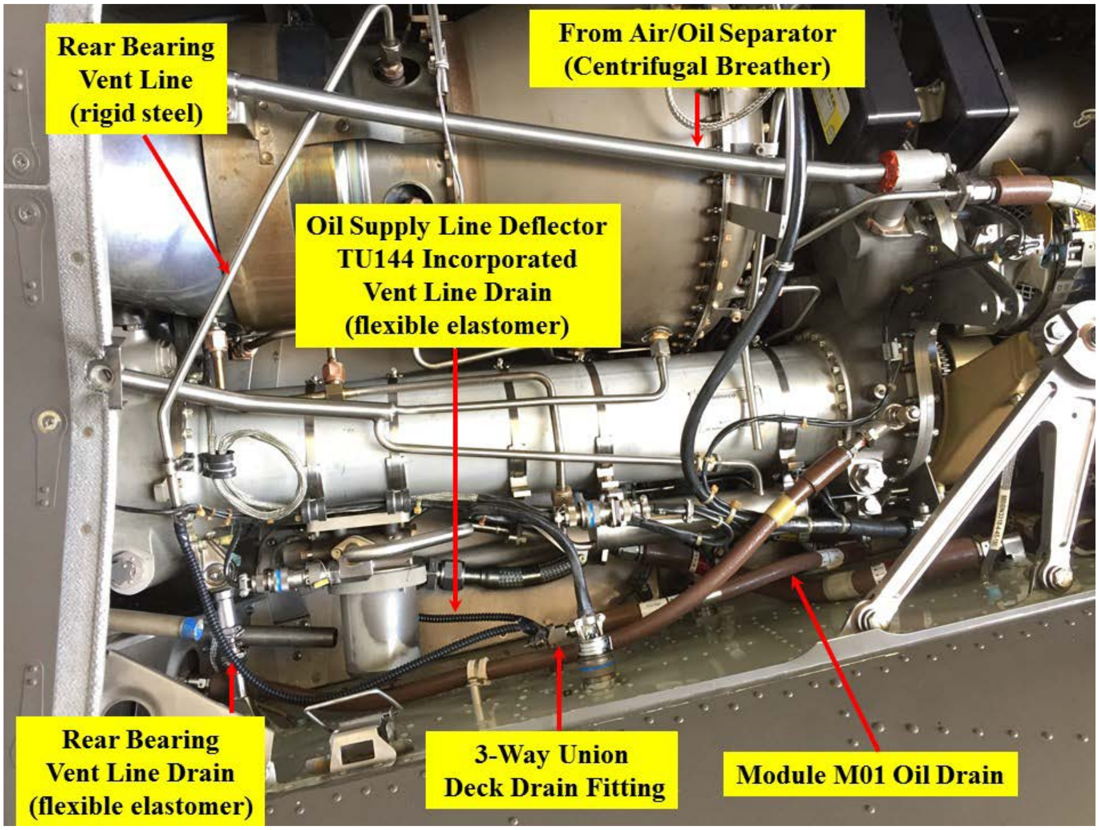

PHOTO 1: PHOTO OF DRAINS ATTACHED TO 3-WAY UNION DECK DRAIN FITTING

PHOTO COURTESY OF SAFRANHE

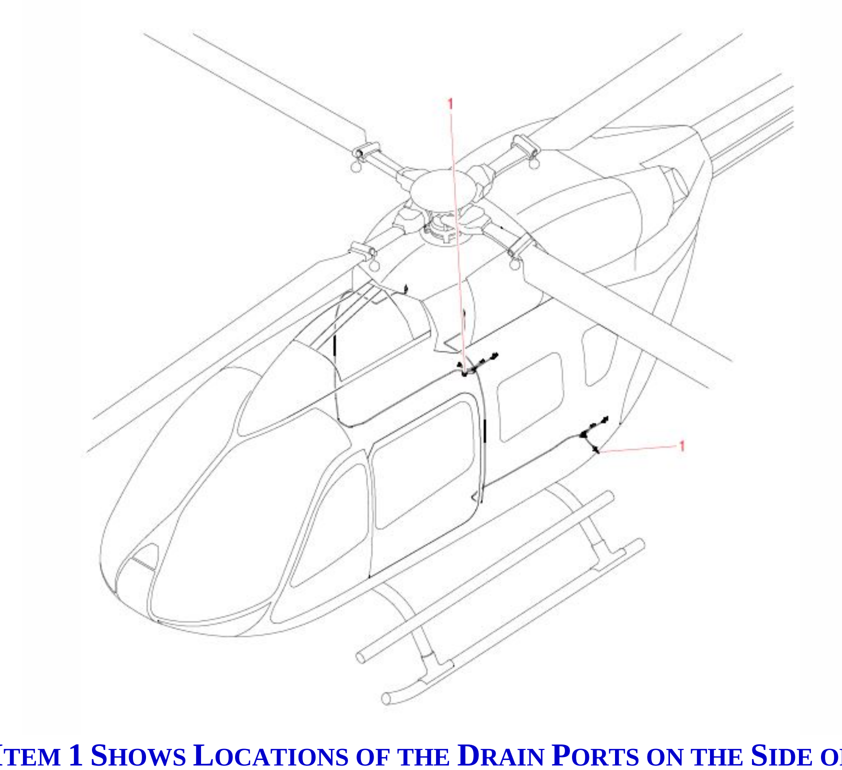

FIGURE 7: ITEM 1 SHOWS LOCATIONS OF THE DRAIN PORTS ON THE SIDE OF THE AIRFRAME

FIGURE COURTESY OF AIRBUS HELICOPTERS

2.1.4 Engine Fuel and Control System Descriptions

The power turbine is designed to operate at a constant rotational speed (constant N2 speed) and the gas generator adapts automatically to changes in power requirements in order to keep the power turbine rotational speed constant by metering the fuel to match the power requirements. The Arriel 1E2 engine is equipped with a hydromechanical fuel control unit (FCU) that ensures metered fuel at a fuel flow and pressure consistent with what is commanded (FIGURE 8).

The main components of the fuel system consist of: 1) the FCU, within the FCU are the high pressure (HP) fuel pump, HP fuel filter, and metering unit (control by the control system), 2) overspeed and drain valve, 3) injection manifold, and 4) injection wheel. These components are the same on all Arriel 1 twin engine model applications. The Arriel 1 E2 is also equipped with low pressure (LP) fuel system intended for aircraft without a booster pump and assures proper fuel supply to the HP pump of the FCU after the engine starts.

During normal operation of the Arriel 1 E2, after the engine starts fuel flows by suction from the aircraft fuel tank through a fuel ejector and a LP fuel filter, both located outside of the FCU, before entering into the HP fuel pump port on the FCU. The fuel then enters the FCU at the HP pump fuel port then travels through the HP fuel filter, metering unit, and out the FCU to the overspeed and drain valve. From there the fuel travels along fuel tubes to the injection wheel located in the combustion chamber.

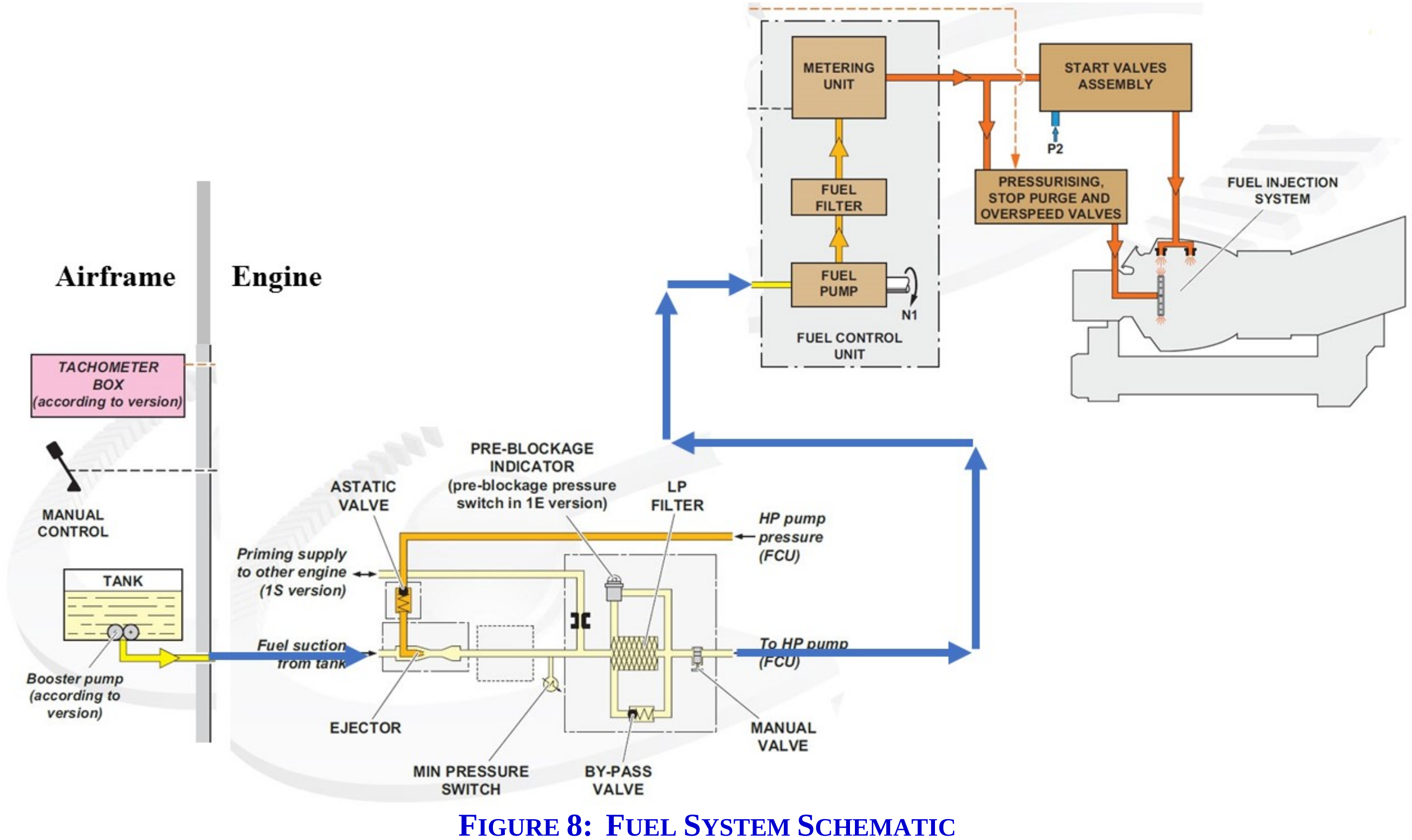

FIGURE 8: FUEL SYSTEM SCHEMATIC

FIGURE COURTESY OF SAFRANHE

The metering unit, which is downstream of the HP pump, is controlled by the control system within the FCU to meter fuel at a desired fuel flow and pressure into the combustion chamber adapts as the power requirement changes. The control system is comprised of acceleration control unit, gas generator speed governor, power turbine governor, and deceleration control unit (**Figure 9**). The engine and the rotor system operate in a closed loop fashion. As the collective pitch changes so does the power commanded; thus, the powered turbine rotation speed (N2) will increase (if less power is commanded) or decrease (if more power is commanded). The power turbine governor includes a flyweight whose centrifugal force matches the datum spring force that can vary with the collective through the anticipator. Such variations will induce pressure changes downstream in the gas generator governor. The force produced by the gas generator governor's flyweight will produce pressure changes downstream and lead to the appropriate movement of the metering needle. The acceleration control unit limits the transient fuel flow variations as a function of compressor outlet pressure (P2) so as to prevent compressor surges during accelerations. The deceleration control unit, which considered part of the metering unit and is not a separate controller, prevents flameouts during deceleration, also as a function of P2.

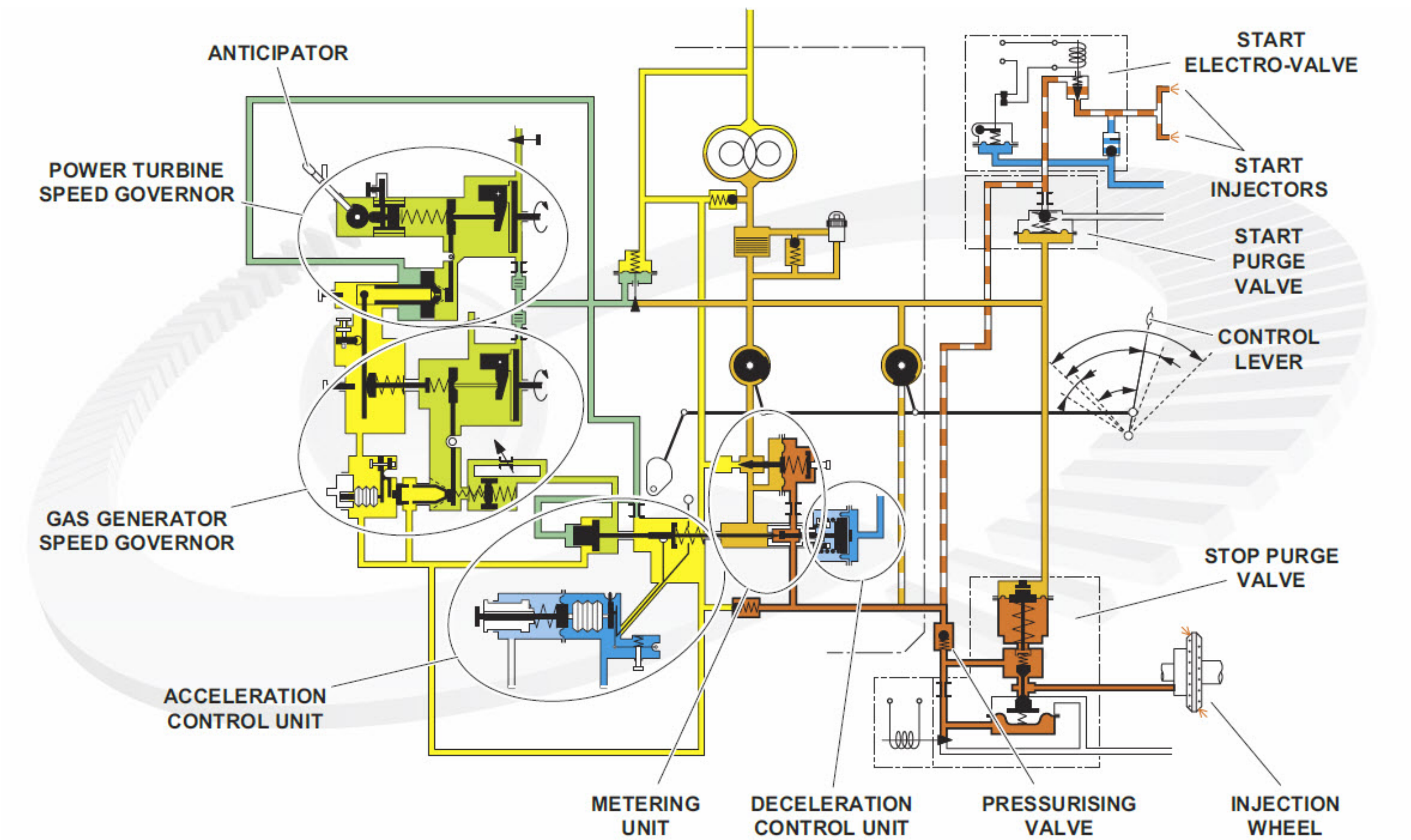

Figure 9: Control System Schematic

Figure Courtesy of SafranHE

2.2 ENGINE HARDWARE EXAMINATION FINDINGS

2.2.1 On Scene Engine Examination – Both Engines

Members from the FAA, SafranHE, Airbus Helicopters, and the National Transportation Safety Board (NTSB) convened at the accident site to document the on-scene condition of the wreckage including the two engines involved in this accident. After the initial on-scene examination was completed, the engines were transported to Atlanta Air Salvage, Atlanta, Georgia for partial disassembly before being shipped to the SafranHE engine facility in Grand Prairie, Texas for additional disassembly and examination. See Airworthiness Group Chairman's Factual Report in the docket for additional on-scene details not discussed below.

General observations for both engines were as follows: 1) engines were found in the correct orientation in the helicopter in relation to the transmission deck, 2) the outside of the engines were thermally damaged consistent with the post-crash fire; the engine thermal damage was greater near the top half of the engines (PHOTO 2), 3) no uncontainments or case breaches were observed, 4) input shaft was continuous and still attached to engine's accessory gearbox and the airframe's main transmission; no visual rotational scoring was noted on the input shaft, 5) the tail rotor drive shaft was continuous and was connected to the airframe's main transmission and tail rotor intermediate gearbox, 6) all the axial compressor blades were present, full length, and no leading edge impact damage was observed (PHOTOS 3 and 4), and 7) all the power turbine blades were present, full length, and no visible damage was observed (PHOTOS 5 and 6).

PHOTO 2: ON-SCENE ENGINE LOCATIONS

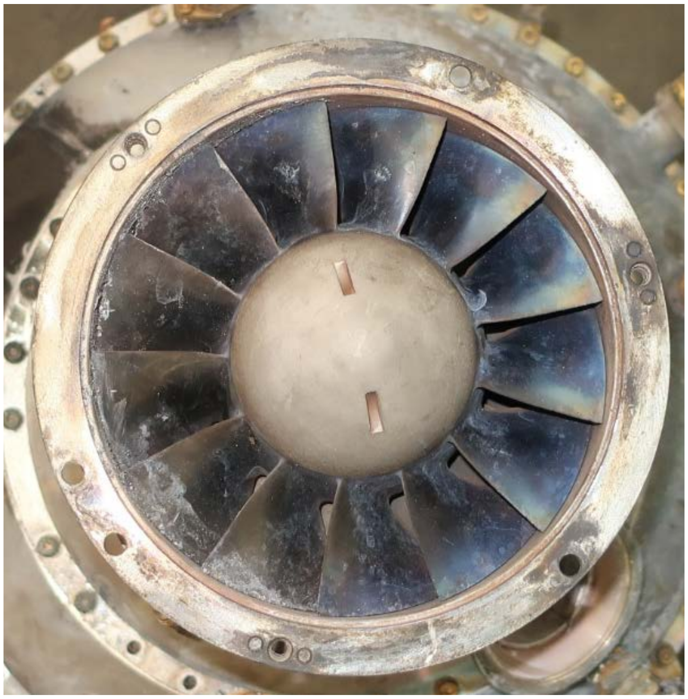

PHOTO 3: ENGINE NO. 1 AXIAL COMPRESSOR

PHOTO 4: ENGINE NO. 2 AXIAL COMPRESSOR

PHOTO 5: ENGINE NO. 1 POWER TURBINE

PHOTO 6: ENGINE NO. 2 POWER TURBINE

Additional No. 1 engine (ESN 47292) observations during the on-scene and partial disassembly were as follows: 1) the gas generator could not initially be turned by hand; however, after the engine starter was removed, an adapter was inserted into the AGB and the gas generator turned freely, 2) the FCU throttle indicator pointer was found at the 0º position (in this position both the main and axillary valves in the FCU are in the CLOSED position) (**PHOTO 7**), 3) the power turbine was turned by hand slightly and continuity was observed with the tail rotor drive output gear in the rear and the transmission shaft in the front, 4) after removal of the engine-to-airframe main transmission gearbox drive shaft, the power turbine was free to rotate and continuity was confirmed from the power turbine through to the engine transmission shaft, 5) the RGB module (M05) was removed and examination of the drive gear slippage mark showed no displacement, and 6) removal of the power turbine module (M04) exposed the power turbine nozzle guide vanes, the second stage gas generator turbine disk and blades, the aft end of gas generator tie-bolt, and the gas generator rear bearing compartment; no damage to any of these items were noted; the rear bearing compartment and the aft end of the gas generator tie-rod were covered in black coke[10]-like material (**Photo 8**).

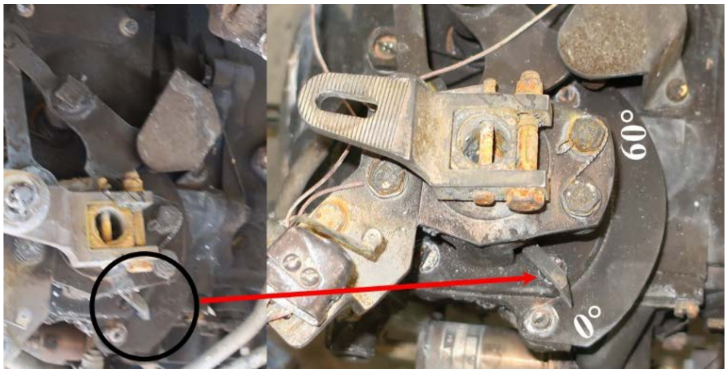

Photo 7: No. 1 Engine FCU Position Pointer Near 0° Position

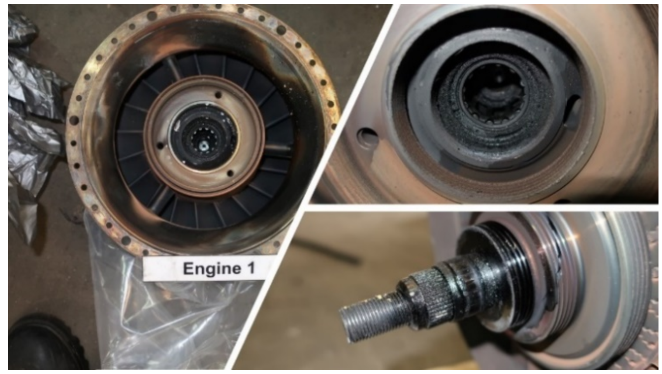

Photo 8: No. 1 Engine Black Coke-Like Buildup on Gas Generator Rear Bearing Area

Additional No. 2 engine (ESN 47346) observations during the on-scene and partial disassembly were as follows: 1) the FCU throttle indicator pointer was found at about the 62º position (**Photo 9**); in this position the main valve is fully OPEN and axillary is in the CLOSED position, 2) the power turbine could not be rotated by hand, even after the transmission shaft had been removed, 3) the RGB module (M05) was removed and examination of the drive gear slippage mark showed no displacement, 4) the RGB was rotated freely by hand confirming continuity though the gear train, 5) with the power turbine module (M04) removed, the power turbine could still not be rotated by hand, 6) removal of the diffuser case exposed the back end of the HP turbine; the aft end of the HP turbine tie-bolt and the rear shaft exhibited thermal distress and wear damage (**Photo 10**), the rotating labyrinth seals (aft shaft also referred to as the piston shaft) exhibited wear with the greatest amount of wear observed on the smallest seal nearest the rear bearing journal, and the rear bearing inner race was fractured and no longer attached to the journal, 7) the rear bearing area was dry without coke buildup, the roller elements were flattened, and the abradable seal lands were heavily gouged and grooved (**Photo 11**), 8) the gas generator rear bearing oil scavenge EMP was removed and partially disassembled (the hollow bolt and electrical magnetic plugs could not be separated) and debris was found (**Photo 12**); some of the particles were magnetic and some debris particles were found bridging the gap between chip detector electrodes, and 9) the remaining external pipes and lines were removed from the rest of the engine and nothing abnormal was noted with the integrity of the fuel, oil, and air lines.

[10] Coke is a solid formed when oil is subjected to high temperatures and experiences thermal breakdown and oxidation. The higher the temperature, the coke can become harder, blacker, and more brittle.

Photo 9: No. 2 Engine FCU Position Pointer Near 62° Position

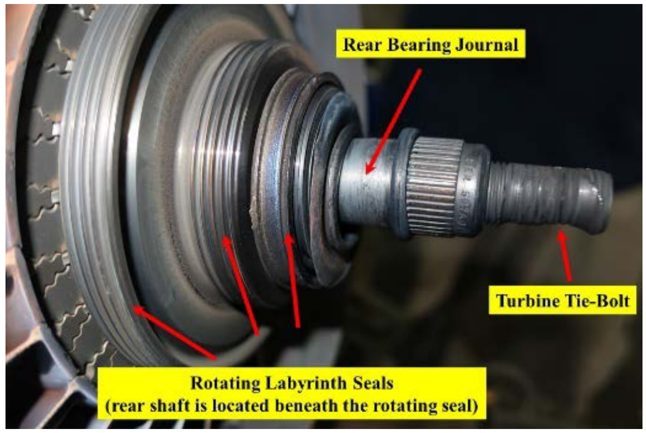

Photo 10: No. 2 Engine Tie-Rod and Seal Damage

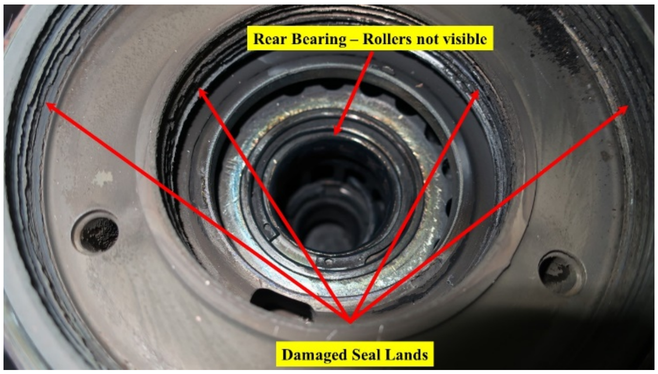

Photo 11: No. 2 Engine Rear Bearing Damage – No Coke Build Up Noted

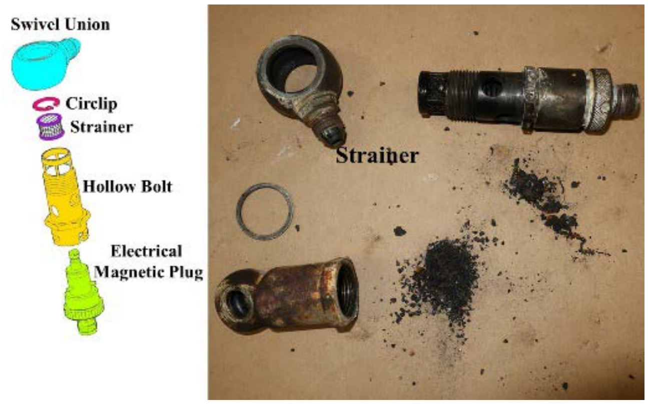

Photo 12: No. 2 Engine Rear Bearing Scavenge Debris

2.2.2 Engine Hardware Examination at SafranHE Grand Prairie Texas Facility

Members from the FAA, SafranHE, Airbus Helicopters, Bureau d'Enquêtes et d'Analyses pour la sécurité de l'aviation civile (BEA), and the NTSB convened at the SafranHE engine facility in Grand Prairie, Texas on March 14, 2018 to disassemble and performed a detailed examination of the two engines involved in this accident. The group completed its work on March 15, 2018. Along with the engine exams, the airframe 3-way union desk drain fittings and their associated lines and drains were also examined and is included with the engine examination findings.

2.2.2.1 Engine No. 1, ESN 47292, and the Left 3-Way Union Deck Drain Fitting

The gas generator (compressor, combustion chamber, and turbine) and the reduction gearbox were disassembled and examined. No evidence of any internal component/part failure was observed and examination of all the compressor and turbine blade tips, their corresponding static structure, and shafts found no contact rub or wear consistent with the engine rotating at impact; the axial compressor blades leading edges were intact and whole but felt rough to the touch. No evidence of internal mechanical failure that would correspond to engine FCU being found in the CLOSED position.

Black coke-like material covered the components of the gas generator rear bearing compartment (**Photo 13**). The rear roller bearing was intact and all the roller elements were in place, had a shiny appearance, and rotated freely and smoothly. The rear bearing support cage was removed and the black coke-like material was found throughout on the inside of the cage where the rear bearing in located as well as on the outside where it is press fit into the bearing housing. Examination of the cage oil passage hole on the outside of the cage found it to be visually covered with black coke-like material while the oil passage from the inside of the rear bearing support cage was visually free of obstruction. To access the depth and compactness (hardness) of the possible oil passage obstruction a pin was inserted into the passage from the inside and it poked through to the outside with no effort (**Photo 14**). The passage was found to be free of any obstruction consistent with just the outside of the hole being covered with thin layer of black coke-like material. During normal operation, oil traveling from the outside of the rear bearing support cage through the oil passage in order to lubricate the bearing. The engine parts and components were shipped to SafranHE in Tarnos and Bordes facilities in France for further evaluation (See Section 3.1.1 No. 1 Engine – ESN 47292 Hardware Examination for details).

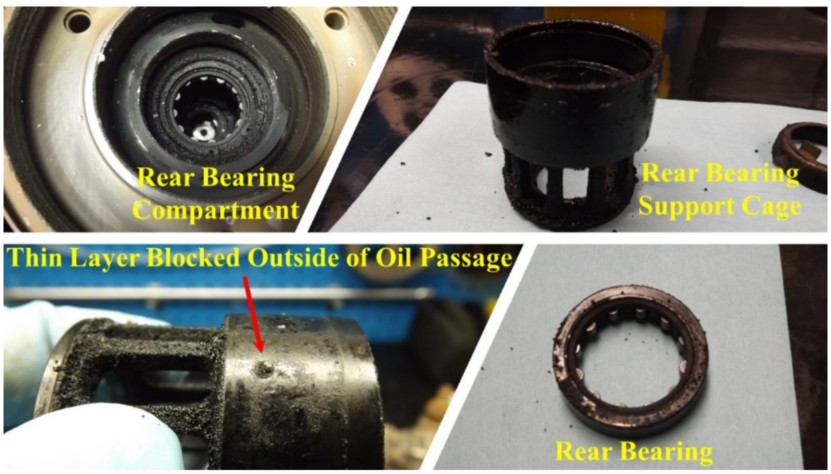

Photo 13: No. 1 Engine Gas Generator Rear Bearing Compartment Covered in Black Coke-Like Material

Photo 14: No. 1 Engine Rear Bearing Support Cage Oil Passage Clear

The gas generator rear bearing oil scavenge duct, oil scavenge line, and the electrical magnetic plug and strainer unit were examined and were found to be clean, without obstructions, and with the presence of oil (**Photo 15**).

PHOTO 15: NO. 1 ENGINE REAR BEARING SCAVENGE

The clamp that secures the rear bearing chamber vent line drain (flexible elastomer line) to the 3-way union deck drain fitting was removed and the remnants of the elastomeric drain were sliced lengthwise to facilitate its removal. The oil vent line drain port was plugged with black coke-like debris and the oil vent line drain itself had an approximately ¾-inch long cylindrically-shaped black coke-like obstruction (**PHOTO 16**). The No. 1 engine oil vent line drain, 3-way union deck drain fitting, and the black coke-like debris were sent to the NTSB's Materials Laboratory in Washington, DC. For further evaluation (See Section 3.2 3-WAY UNION DECK DRAIN FITTING EVALUATION AT THE NTSB for details).

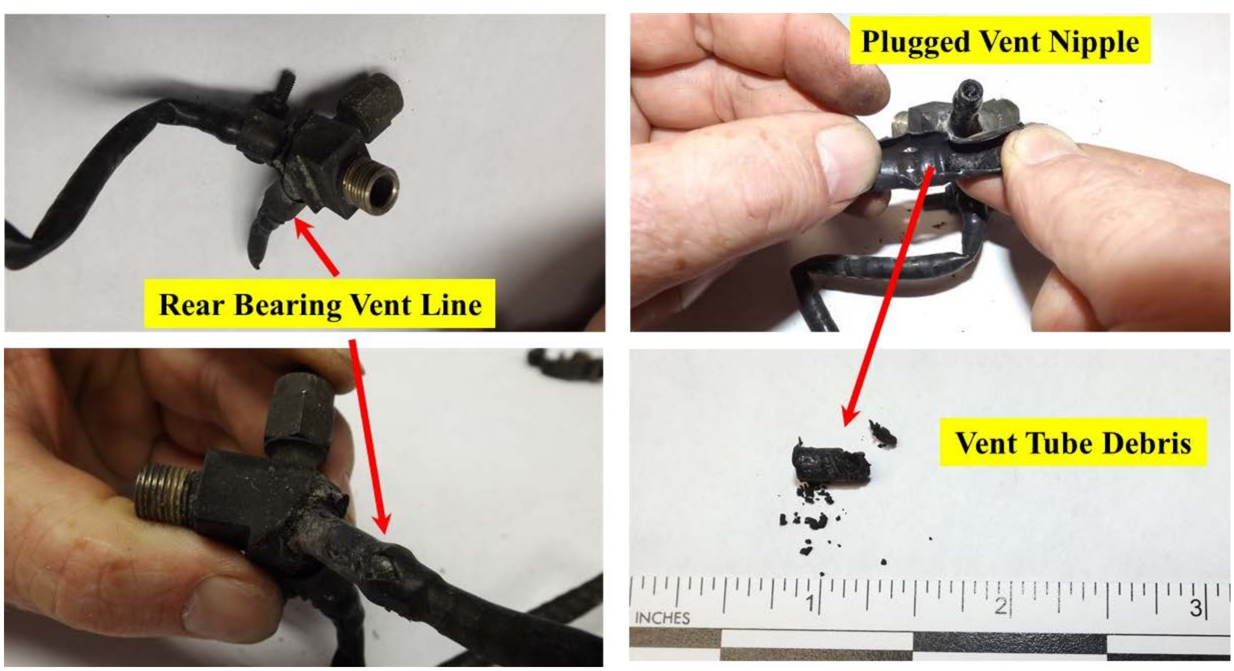

PHOTO 16: NO. 1 ENGINE VENT LINE OBSTRUCTION AT THE DECK FITTING

2.2.2.2 Engine No. 2, ESN 47346, and the Right 3-Way Union Deck Drain Fitting

The gas generator (compressor, combustion chamber, and turbine) and the reduction gearbox were disassembled and examined. The axial compressor wheel exhibited no appreciable blade damage but did exhibit circumferential bluish heat distress on both the forward and aft sides hub as well as on the surface of the blades; the leading edges of the blades felt rough to the touch. The outside of the aluminum inlet nose cone was wrinkled consistent with exposure to high temperatures. The axial compressor shaft exhibited bluish heat distress located at three distinctive axial locations (360° circumferentially around the shaft); the forward most was in-line with the No. 1 bearing (gas generator front bearing), the middle in-line with the bevel gear, and the rearmost in-line with the No. 2 bearing (gas generator rear bearing) (**Photo 17**). Both the gas generator front bearings were visually undamaged. The leading edge exducer part of a centrifugal compressor blade exhibited contact wear; however, the wear was not present on all the exducers. The compressor front cover circumferential scoring of around the aft side outer edge; the scoring was along an approximately 180° arc and was in-line with the wear observed on the centrifugal compressor exducer blade (**Photo 18**). The No. 1 and No. 2 bearings were intact, all the roller balls were present, and all appeared in good condition; the bearings did however exhibit slight bluish discoloration.

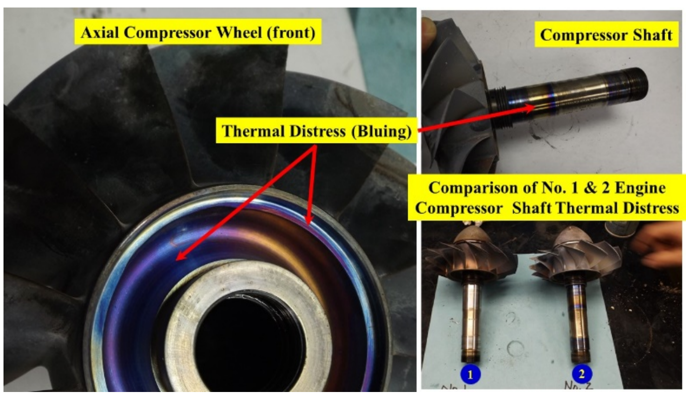

Photo 17: No. 2 Engine Axial Compressor Heat Distress

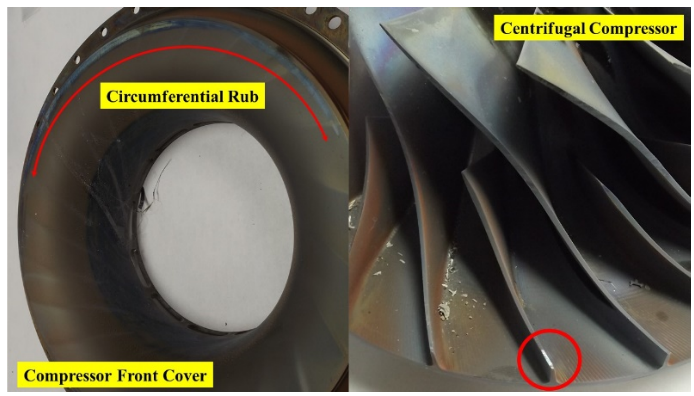

Photo 18: No. 2 Engine Centrifugal Compressor Contact Wear

The blades on both stages of the gas generator turbine exhibited light contact wear on the tips; corresponding circumferential scoring was noted on the 1st and 2nd stage gas generator turbine shrouds in-line with the blade running path (**Photo 19**). Such blade tip wear may lead to a degradation in engine performance and instability in the combustion section. Instability in the combustion section may result in incomplete combustion, smoke out the back of the engine and, possibly, engine flameout. The power turbine blades are secured into the power turbine disk by locking tabs that crimped radially to prevent the blades from sliding or migrating out of the individual blade slots.

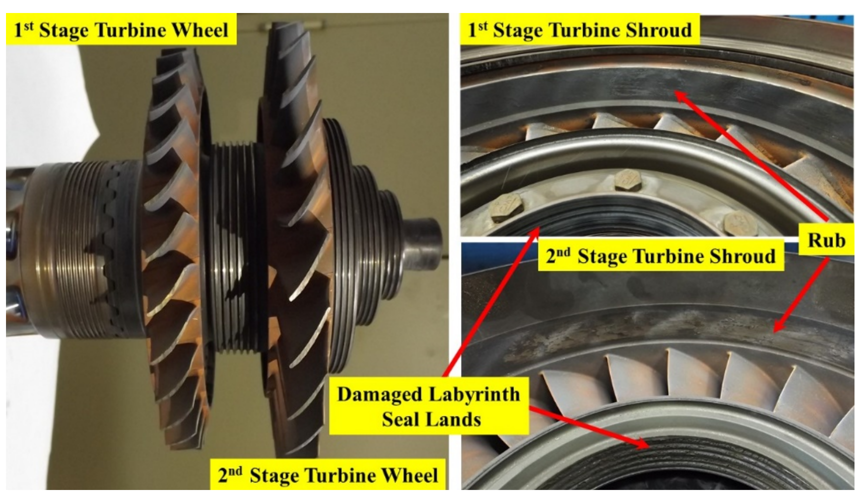

Photo 19: Contact Rub in the Gas Generator Area

Examination of the power turbine found that all the blades were present but about half had translated aft in the blade slot slightly and that the corresponding locking tabs on the front of the disk were no longer crimped but were bent straight. All the locking tabs were present and whole under the blade roots. The shroud of the power turbine nozzle guide vane exhibited a localized area around the inner vane ring aft face with wear and raised/gouged material. The raised area was distinctive and not continuous, a little over 180º arc, and was more consistent with a static impact mark and slight rotation than a pure rotating impact mark (**PHOTO 20**).

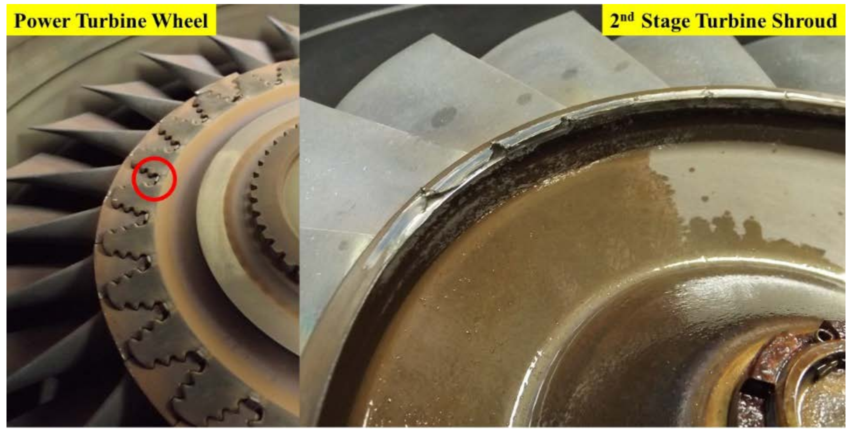

PHOTO 20: POWER TURBINE CONTACT DAMAGE – RED CIRCLES SHOWS LOCK TAB BENT STRAIGHT

Examination of the gas generator rear bearing compartment revealed that it had no significant amount of black coke-like material like what was observed in the No. 1 engine (**PHOTO 21, 'A'**). This is consistent with the condition of the rear bearing chamber as observed at Atlanta Air Salvage in Atlanta. The rear bearing housing was removed and it showed some black coke-like material. Examination of the rear bearing support cage showed that some black coke-like material as well but not the amount that was observed on the No. 1 engine. No obstruction of the rear bearing support cage oil passage was noted (**PHOTO 21, 'B'**). Removal of the rear bearing from its support cage revealed that all the roller elements as well as the roller cage was still present and that all the roller elements were flattened flush the cage; the rear bearing was dry and lacked any lubrication (**PHOTO 21, 'C'**). The examination of the cavities around the rear bearing's chamber showed that they were dry without signs of oil or coke and there were no indications of a bearing compartment fire. The gas generator rear bearing compartment components were shipped to SafranHE in France for further evaluation (See Section 3.1.2 NO. 2 ENGINE – ESN 47346 HARDWARE EXAMINATION for details). The gas generator rear bearing oil supply, scavenge, and vent lines and drains, were examined and were found to be clean without obstructions. The No. 2 engine oil vent line, 3-way union deck fitting, and the black debris were sent to the NTSB's Materials Laboratory in Washington, DC. For further evaluation (See Section 3.2 3-WAY UNION DECK DRAIN FITTING EVALUATION AT THE NTSB for details).

PHOTO 21: NO. 2 ENGINE REAR BEARING COMPARTMENT CONDITION

2.3 ENGINE OIL SYSTEM REQUIREMENTS, MAINTENANCE, AND INSPECTIONS

2.3.1 Arriel 1 E2 Approved and Recommended Engine Oils

The Arriel 1 E2 engine maintenance manual (EMM), TASK 71-00-02-940-801-A01 titled FUEL – LUBRICANTS AND SPECIAL PRODUCTS), provides tables of recommended and authorized fuels and lubricants for the engine; SUB-TASK 71-00-02-940-002-A01 titled LUBRICANTS deals with the engines oils and will be the only SUB-TASK discussed in this section. The oil tables provide the various differing kinematic viscosities[11] and different categories. The viscosity range listed is from 3cSt to 7.5 cSt at 100℃ and the categories are standard, corrosion inhibiting, and high thermal stability (HTS). Based on the oil type selected, there are temperature limitations and differing oil drain frequency requirements. In the NOTES section it states:

> The oil type stipulated for normal use is the 5cSt fluid synthetic oil specified under the heading "RECOMMNEDED OILS" and "NORMAL USE". The oils mentioned under the heading "AUTHORIZED USE" can be used but are not recommended, unless otherwise specified.

According to the AMC engine logbook, both engines were originally delivered new installed in the accident helicopter MBB-BK 117 C-2, helicopter SN 9474 (**ATTACHMENT 3**), and were serviced with Mobil Jet II (See **TABLE 3**). According to the AMC engine logbooks and Task D 1040 (Engine Tracked Item) Drain and Replace engine oil 300 hours/12 months TASK 79-00-00-610-801-A01 (See Section 1.11 AIRCRAFT FLIGHT LOGS **TABLE 3**), the accident engines were serviced with Mobil Jet II through its entire operational life. The Arriel 1 E2 EMM lists Mobile Jet II as a "NORMAL USE" standard approved synthetic oil

[11] Kinematic viscosity is essentially a measure of how easily the oil will flow; it is measure of the fluid's resistance to flow and shear under gravity. The units to indicate the viscosity is referenced to as centistokes (cSt); 1 centistoke = 1 millimeter squared per second ($1mm^2/s$). The higher the centistoke number the less viscous the liquid; meaning it takes less time to flow the given distance.

with 5cSt rating with no restriction on the oil draining frequency associated with its use but with the following engine start operational limitation: Use 5cst oil with NATO code 0-156 [Mobil Jet II is designated at NATO symbol of 0-156] for normal use in ambient temperature between -30°C and +50°C (-22°F to 122°F).

Turbomeca SL No. 1642/96/Arriel/25, 2nd issue, dated May 15, 1996, (was the most current version of the SL at the time of the accident) stated that under certain operating temperature condition the use of 7.5cSt oil is better than 5cSt oil in reducing carbon formation (**ATTACHMENT 4**).

2.3.2 Engine Maintenance Manual Module 03 and Oil System Inspections

Since the No. 2 engine showed evidence of a gas generator rear bearing failure and the rear bearing of the No. 1 engine was covered in black coke-like material, this section will focus only on oil system inspection requirements related to that area or module - Module M03. All the oil inspection requirements that will be discussed are from the Turbomeca Arriel 1 E2 EMM that were current at the time of the accident; Arriel 1 E2 EMM No. X 292 M3 452 2, update No. 22, dated June 30, 2017 (Original issue dated October 15, 2005).

Since the Arriel 1 E2 engine is modular, each module has its own inspection frequency. The time between overhaul (TBO) in hours is the maximum authorized operational time before the item or module is required to be overhaul based on normal operating conditions. Within the CHAPTER 5 AIRWORTHINESS LIMITATION Section of the Arriel 1 E2 EMM is a table of mandatory TBOs (TASK 05-15-00) for the engine/modules/equipment; for the Module M03 with Post TU 195, 202, 244, 277, and 278 incorporated, the mandatory TBO is stated as 3,600 hours (**FIGURE 10**). Both of the event engines complied with the above listed TUs upon delivery of the engines Turbomeca (See **ATTACHMENT 2**) and this TBO agrees with one stated in the AMC OpsSpec Section D102 (See Section 1.3 Operations Specifications, subsection e) of this report. According to AMC logbook records, both engines had accumulated slightly over approximately 2,714 hours TSN at the time of the accident (See **TABLE 2**); therefore, no mandatory overhaul of Module M03 was required nor had it been accomplished yet.

72-43-00-01-001	Module 03 assy - Gas generator	Every 3,600	FH	TSO
Component standard for above task : **POST TU 195, POST TU 202, POST TU 244, POST TU 277, POST TU 278**				
72-43-00-01-001	Module 03 assy - Gas generator	Every 3,000	FH	TSO
Component standard for above task : **POST TU 195, POST TU 202**				
72-43-00-01-001	Module 03 assy - Gas generator	Every 2,500	FH	TSO
Component standard for above task : **Any other standard**				

FIGURE 10: TURBOMECA ARRIEL 1 E2 CHAPTER 5 – TASK 05-15-00-201-801-A01

TABLE 5 provides a list of pertinent oil system or Module M03 inspection requirements and the task frequencies based on the engine configuration from the CHAPTER 5 SCHEDULED INSPECTIONS REQUIREMENT TASK 05-20-00 unless otherwise noted. All the TUs listed in the applicability column had been incorporated into both engines at the time they were delivered and installed on the accident helicopter MBB-BK 117 C-2, SN 9474 (See **ATTACHMENT 2**).

TABLE 5: PERTINENT OIL SYSTEM AND MODULE M03 TASKS					
EMM TASK DESCRIPTION	**TASK NUMBER**	**INTERVAL (FLIGHT HOURS +TOLERANCE) R = REQUIRED OP = OPTIONAL**	**APPLICABILITY**	**AMC ZONAL INSPECTION**	**NOTES**
Inspection of oil level in tank	Engine Installed Refer to Helicopter Manual	Before each flight (R)	ALL	Pre-flight airworthiness check	This agrees with the MBB-BK 117 C-2 FM preflight check (R)
Visually examine the engine and the engine floor for leakage TASK 05-20-10-201-804-A01	Engine Installed	After last flight daily (R)	ALL	Pre-flight airworthiness check	MBB-BK 117 C-2 FM allows before first flight (R)
Visually check that there are no leaks on the rear bearing oil ducts TASK 05-20-10-201-804-A01	Engine Installed	After last flight daily (R)	ALL	Pre-flight airworthiness check	MBB-BK 117 C-2 FM allows before first flight (R)
Examine the visual blocker indicator of the oil filtering element TASK 05-20-10-201-804-A01	TASK 72-61-00-900-803-A01 Engine Installed	After last flight daily (R)	ALL	Pre-flight airworthiness check	MBB-BK 117 C-2 FM allows before first flight (R)
Oil Sample Procedure	TASK 71-02-08-280-801-A01 Engine Installed	100 (R)	ALL	D 0520 (100 hours)	This is an AMC inspection requirement per their AAIP. This is not a CHAPTER 5 engine requirement. This oil sampling is used for Spectrometric Oil Analysis Program (SOAP) and RULER™ (see Section 2.3.3.2 OIL ANALYSIS REQUIREMENTS for details)
Inspection and replacement of	TASK 72-61-00-900-802-A01	400+40	Post TU 232	D 1040 (300 hours/ 12 month	If particles present, check if particles per

TABLE 5: PERTINENT OIL SYSTEM AND MODULE M03 TASKS

EMM TASK DESCRIPTION	TASK NUMBER	INTERVAL (FLIGHT HOURS +TOLERANCE) R = REQUIRED OP = OPTIONAL	APPLICABILITY	AMC ZONAL INSPECTION	NOTES
the oil filtering element TASK 05-20-10-201-840-A01	Engine Installed or Removed	(R)[12]			TASK 71-02-07-280-802-A01
Inspection and cleaning of the electrical magnetic plugs at oil outlet TASK 05-20-10-201-840-A01	TASK 79-38-00-210-801-A01 Engine Installed or Removed	400+40 (R) Every 12+1 months	ALL	B 1040 (300 hours/ 12 months)	If particles present, check particles per TASK 71-02-07-280-802-A01
Inspection of the rear bearing (for clogging) TASK 05-20-10-201-850-A01	TASK 72-43-10-280-801-A01 Engine Installed	600+50 (R)[13]	Post TUs 274, 281, 283, and 284*	B 310 (600 hours)	Perform drain flow test, greater than 50 milliliters is acceptable, otherwise check for clogging
Oil draining TASK 05-20-10-201-855-A01	TASK 79-00-00-610-801-A01 Engine Installed	800+80 (R) Every 24+2 months AMC performs this task every 300 hours	No use ROYCO 560, ASTO 560 and ETO 2370 type oils[14] Air Methods uses Mobile Jet II	D 1040 (300 hours/12 months)	Use lubes per TASK 71-00-02-940-801-A01
Inspection and check of the strainer of the oil scavenge line of the gas generator rear bearing TASK 05-20-10-201-855-A01	TASK 79-38-00-210-801-A01 Engine Installed or Removed	800+80 (R)[15]	Post TUs 274, 281, 283, and 284*	B 310 (600 hours)	If particles view in comparison with TASK 71-02-07-280-802-A01
Cleaning of the rear bearing of the free turbine nozzle guide vane (NGV)	TASK 72-43-10-100-801-A01	1,200+50 (OP)	Post TUs 274, 281, 283, and 284*	B 2210 RT (1,200 hours)	Descale per TASK 71-00-02-940-801-A01. Decarbonize orifices with drill bit

[12] The inspection frequency was every 150 hours+15 hours for Pre TU 232.
[13] The inspection frequency was every 100 hours+10 hours for Pre TUs 274, 281, 283, and 284 incorporation.
[14] If these oils are used the drain interval is 400 hours+40 hours or every 12 months+1 month.
[15] The inspection frequency was every 100 hours+10 hours for Pre TUs 274, 281, 283, and 284 incorporation.

TABLE 5: PERTINENT OIL SYSTEM AND MODULE M03 TASKS					
EMM TASK DESCRIPTION	**TASK NUMBER**	**INTERVAL (FLIGHT HOURS +TOLERANCE) R = REQUIRED OP = OPTIONAL**	**APPLICABILITY**	**AMC ZONAL INSPECTION**	**NOTES**
	Engine Removed				
Removal, cleaning, and installation of the oil-scavenge line TASK 05-20-10-201-865-A01	TASK 72-43-00-610-801-A01 Engine Installed or Removed	1,200+50 (OP)	Post TUs 274, 281, 283, and 284*	B 2210 RT (1,200 hours)	Clean with de-scaler and decarbonize with drill bit
Make sure the three hollow struts for the passage of the rear bearing oil tubes are serviceable TASK 05-20-10-201-865-A01	TASK 72-43-10-210-801-B01 Engine Installed or Removed	1,200+50 (OP)	Post TU 281	B 2210 RT (1,200 hours)	Insert 1.68 mm (0.067 inch) diameter rod into hole – acceptable, otherwise replace union(s)

* Turbomeca issued SB 292 72 0215 titled M03 MODULE (GAS GENERATOR) MODIFICATION OF REAR BEARING. INCORPORATION OF MODIFICATIONS TU 274 - 281 - 283 - 284 originally issued on May 5, 1997, with the most current revision being update No. 3 issued on April 2002. The purpose of TU 274 was to improve the mechanical strength of the free turbine nozzle guide vane deflector by changing the material of the deflector and installing an adjusting washer thus preventing the formation of a crack which can result in rubbing of the free turbine disk requiring engine removal. It should be noted that TU 274 does not impact the rear bearing lubrication and was included due to mechanical reason with the other TU that do impact the rear bearing lubrication. The purpose of TUs 281, 283, and 284 were to improve cooling of the gas generator rear bearing and reduce the formation of coke deposits in that area. TU 281 increased lubrication jet diameter of the gas generator rear bearing from 1mm to 2mm (0.04- to 0.08-inch) and added a jet on the oil supply union. TU 283 added a chamfer to inside of the oil scavenge line to facilitate oil scavenging, and silver plated of the seal. TU 284 increased area of the passageway of the oil scavenge channel in the gas generator rear bearing housing from 6mm to 8mm (0.24- to 0.32-inch). As mentioned before, all the TUs and the SB were complied with when the engines were installed new into the accident helicopter.

2.3.3 Oil Filter, Magnetic Plug, Oil Inspection Requirements

2.3.3.1 Oil Filter Inspection and Magnetic Plug Inspection Requirements

Inspection of the oil filtering element (TASK 72-61-00-900-802-A01) and the EMPs (TASK 79-38-00-900-801-A01) are required every 400+40 hours for ALL configurations; the MMPs located in the Module M01 (TASK 72-61-00-900-805) and Module M05 (TASK 72-15-00-900-801-B01) are required to be inspected every 30+3 hours for ALL configurations. The Modules M01 and M05 MMP inspections are included for reference only and will not be discussed further. If particles are found on either the MMPs or the EMPs, an oil system particle inspection, TASK 71-02-07-280-801-A01 is to be performed. The AMC maintenance program has the EMPs inspection interval every 300 hours (Turbomeca recommends every 400 hours (See **Table 5**)) and was last checked on both engines on July 26, 2017 (B1040 300 hour/12 month – See **Table 2**) with no unusual findings.

TASK 71-02-07-280-801-A01 provides the method of collecting particles from the MMP/EMPs, shipping instructions to an approved laboratory analysis, and the required engine data to accompany the sample. The particle evaluation criteria are set forth in TASK 71-02-07-280-802-A01. The collected particles are visually inspected using a 6x magnifying glass and based on the quantity and particle type a decision on the follow-on maintenance level (Level A = minor, Level B = light, and Level C = Heavy) is determined. Level A maintenance calls for draining and rinsing engine oil system, clean MMP/EMPs and strainers, and return-to-service under monitoring. Furthermore, if the engine is monitored using a SOAP, a comparative analysis from the previous samples should be conducted. Level B requires an analysis of the particles and based on that analysis, specific tasks are called out to be performed before the engine is returns to service; combination of draining, rising, cleaning and possibly a ground run before a return-to-service under monitoring. If the particles generation persist, then a Level C maintenance is required. Level C means the engine is unserviceable and module level removal and replacement is to be performed followed by draining and rinsing engine oil system; decision of which modules to remove should be conducted in coordination with Turbomeca.

2.3.3.2 Oil Analysis Procedures and Criteria

AMC had both accidents engines on a SOAP program (this is optional and not part of the CHAPTER 5 OF SCHEDULED INSPECTIONS) with the oil sample spectrometric analysis taken every 100 flight hours per their OpsSpec. TASKs 71-02-08-280-801-A01 and 71-02-08-280-802-A01 provide the instructions for collecting and analyzing the oil samples. TASK 71-02-07-280-802-A01 titled PARTICLES IN THE OIL SYSTEM - SAMPLING PROCEDURE SPECIAL PROCEDURE provides the procedures for collecting samples, quantity to be collected, the necessary information to accompany the sample, and where to send the sample for analysis while TASK 71-02-08-280-802-A01 titled ANALYSIS METHOD AND CRITERIA SPECIAL PROCEDURE provides the analysis method and criteria for the SOAP analysis. According to TASK 71-02-08-280-801-A01 the oil samples should be sent to Turbomeca or a laboratory qualified by Turbomeca that is listed on their "List of approved laboratories".

The SOAP program can be used to identify the condition of the engine oil, such as oil viscosity, wear materials, contamination, and acidity of the oil. SOAP results can be used not only to identify the condition of the oil at one point in time but also be used to trend the health of the oil over time. Discussions with AMC indicate that the results of the SOAP analysis was used to access the health of the oil engine at a particular point in time, and depending on the results, if any maintenance action should be taken in accordance with the Turbomeca criteria (See **FIGURE 14**). The oil analysis criteria are used to evaluate the composition, concentration (parts per million (ppm)), and accumulation rate (m - milligram/hour (mg/hr or ppm/hr)) of the material suspended in the oil as well as the oil quality. The suspended material is either wear elements, those elements associated with the oil system such as bearing and gears, contaminant elements that are external to the engine such as silicon or pollution, or a combination of both. Only wear materials in concentrations of ppm are listed in the inspection criteria; no contaminate elements are listed. The most predominant wear element is iron (Fe), which is found through the oil system but is the main constituent of the bearing roller elements and races. All the concentration values are corrected values (Corrected Concentration (CT)) which considers fluctuations in oil quantity due to oil leaks and oil consumption and subsequent addition of oil. Different CT formulas are provided for calculating the CT based on added oil, engine operating time between SOAP samples, and oil consumption rates; if oil is added at a rate of 0.01 liters per hour (l/hr) then there is no correction need and CT = C; however if oil is added at a rate greater than 0.01 l/hr, Turbomeca specifies a formula for CT (**EQUATION 1**). To ensure that an accurate CT is calculated, TASK 71-02-08-280-801-A01 lists specific information that should accompany the sample (**FIGURE 11**). In comparing **EQUATION 1** and **FIGURE 11** requirements, the total volume in the tank at the time oil sample is taken is not a required piece of data to record.

CT_b = CT of current sample (ppm)
CTa = CT of previous sample (ppm)
C_b = Concentration of current sample after correction coefficient is applied (ppm)
C_a = Concentration of previous sample after correction coefficient is applied (ppm)
V = Total Volume in tank (liters)
V_b = Volume added between current and previous sample

$$\mathbf{CT_b = CT_a + C_b + C_a[(V_b/V) - 1]}$$

EQUATION 1: CORRECTED CONCENTRATION VALUE WHEN OIL ADDED GREATER THAN

(4) Labeling

Mention the following information on the sample label and on the analysis request sheet:

- Date of sampling
- Oil specification
- Engine type
- Engine No.
- Number of hours since the last installation
- Number of operating hours since the last oil draining
- Quantity of oil required to complete oil level since the last sample has been taken and number of replenishments
- Reason for taking sample
- Required analysis type(s) (SOA - RULLER ™ or the two).

Figure 11: Information That Should Accompany the SOAP Sample (TASK 71-02-08-280-801-A01)

Once the oil samples have been collected, TASK 71-02-08-280-802-A01 specifies that the samples be sent to either Turbomeca – avenue du 1er mai – DT/MPE Laboratoire analyse – 40220 Tamos Cedex France or to an external laboratory qualified by Turbomeca as listed on the list of approved laboratories on TOOLS[16]. Currently (as of September 2018), AMC has been sending their Turbomeca oil samples to Spectro®|Jet-Care® in Cedar Knolls, New Jersey; however, they were also sending samples to the Spectro®|Jet-Care® facility in Crowley, Texas. Spectro Inc.® and Jet-Care® are both on the Turbomeca approved laboratories list on TOOLS (**Figure 12**).

List of laboratories approved by Safran Helicopter Engines

LIST OF LABORATORIES QUALIFIED SOA FOR ENGINES IN SERVICE

LABORATORY NAME	COUNTRY
Aviation Laboratories	UNITED STATES of AMERICA
SPECTRO INC	UNITED STATES of AMERICA
Jet Care	UNITED STATES of AMERICA

LIST OF OTHER LABORATORIES QUALIFIED SOA FOR ENGINES IN SERVICE

LABORATORY NAME	COUNTRY
Intertek Testing Services (Melbourne)	AUSTRALIA

Figure 12: TOOLS Showing Approved SOAP Laboratories

[16] TOOLS is an on-line customer portal to manuals, training, spare parts ordering, engine health monitoring, etc.

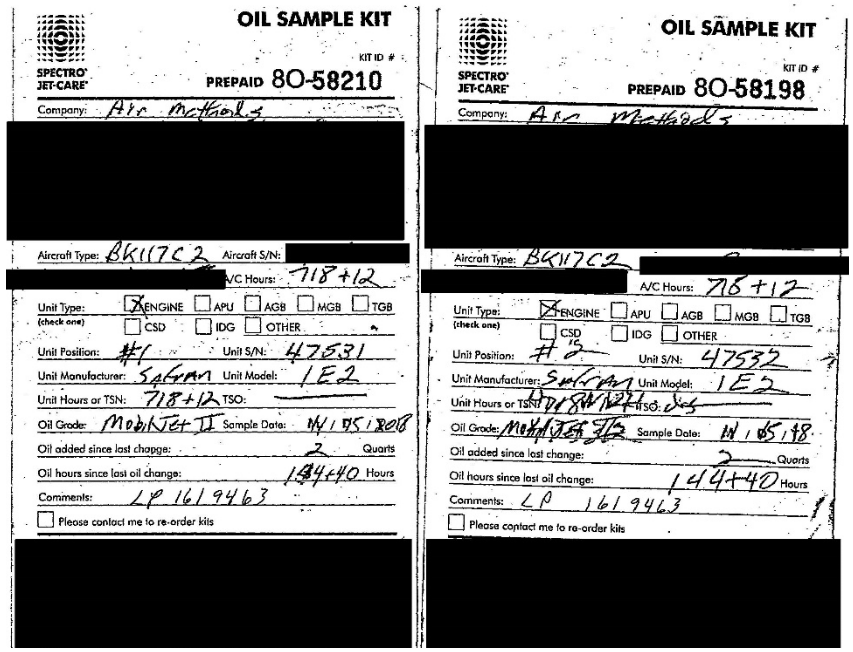

Figure 13: Exemplar AMC Oil Sample Kit Data Sheet

Figure 13 is an exemplar sample of the Oil Sample Kit data sheet that AMC now provides Spectro®|Jet-Care® in Cedar Knolls, New Jersey along with the oil sample for analysis. Comparing the Oil Sample Kit data sheet and the data requirements provided in TASK 71-02-08-280-801-A01 (See **Figure 11**) shows that the specified data is captured and provide on the data sheet.

The MBB-BK 117 C-2 FM includes a Record of Oil Types (ROOT) sheet that can be filled out by the helicopter operator when oil is added to the engine. The intent is to avoid mixing different oil types and to make available to the pilot the applicable oil used. In filling out the ROOT, the operator records the engine oil type, viscosity, and date the oil was added, but does not have a place for quantity added. This ROOT sheet is not used for SOAP analysis since this does not provide the necessary documentation to perform the evaluation properly; instead the operator is supposed to record oil replenishments, drains, and oil levels, etc. either in the engine logbook or a dedicated form. In the MBB-BK 117 C-2 FM, Section 2 Limitation, the oil quantities for each engine tank are as follows: total tank quantity is 5.50 liters, usable oil minimum quantity is 3.50 liters, usable oil maximum quantity is 5.10 liters, and unusable oil quantity is 0.40 liters.

Based on the calculated CT values and contamination accumulation rate, alert and removal levels are established, and SOAP inspection frequencies can be modified as necessary. Alerts are when the concentration or accumulation rate are such that the engine oil must be monitored and inspected more frequently whereas removal levels are such that the engine must undergo a maintenance procedure to correct the issue. **Figure 14** provides the allowable CT limits for various wear materials and the required action based on those concentrations.

	Fe	Cu	Cr	Ni	Frequency	Notes
Concentration CT (ppm)	Fe < 7.5	Cu < 2			(1)	None
Alert concentration CT (ppm)	7.5 ≤ Fe < 15	2 ≤ Cu < 4			5 hours or at the last flight of the day	3, 4, 5
Removal concentration CT (ppm)	Fe ≥ 15	Cu ≥ 4	0.7 (if Fe > 6)	0.8 (if Fe > 6)		2, 6
Removal rate m (mg/hr)	m ≥ 0.5					1, 6

Figure 14: SOAP Alert and Removal Criteria

In addition to the SOAP analysis that evaluated particles that are suspended in the oil, TASK 71-02-08-280-802-A01 also provides a method to access the quality of the oil, essentially the remaining useful life evaluation routine (RULER™) test. Additives are commonly added to oils to help increase lubricity and reduce oxidization (antioxidant). A measure of the decrease in the health (quality) of the oil is a decrease in antioxidant, increase in acidity, and decomposition of the lubricant, all which can lead to an increase in coke formation. TASK 71-02-08-280-802-A01 specifies the minimum rate of antioxidants is 70% and below that value, it is strongly recommended to change the oil. According to AMC, they do not perform the RULER™ test themselves nor is it performed or required to be performed by their approved SOAP analysis vendors.

As mentioned previously in this section, the SOAP program outlined by Turbomeca identified wear material concentration values as CT values by considering fluctuations in oil quantity due to oil leaks and oil consumption and subsequent addition of oil to establish the appropriate value for trending purposes. Reviewing the SOAP test reports for the accident engines (**Figures 15** and **16**) revealed that the oil quantity added to each engine was the same amount (in quarts) for each sample time. A review on the aircraft flight logbook entries (See **Table 3**) for the same time frame (November 2016 - August 2017) as the SOAP sample results showed the following: 1) that both engines were serviced with new oil on January 12, 2017 and July 10, 2017; 251 hours between oil changes which is within the Turbomeca (every 800 hours) and AMC AAIP (every 300 hours) requirements, 2) oil samples for both engines were taken within every 100 hours in accordance with the Turbomeca and AMC AAIP (both required every 100 hours), and 3) on April 11, 2017 and July 20, 2017, a ½ quart of oil was added to each engine. When compared the SOAP test sheets with the aircraft flight logbook entries for oil additions, the quantities did not match. For example, between the April 3, 2017 and the May 15, 2017 SOAP tests, the test sheet indicates that 2 quarts were added to each engine; however, only a ½ quart was documented in aircraft flight book and between May 15, 2017 and the July 7, 2017 SOAP tests, the test sheet indicates that 1 quart were added to each engine; however, 0 quarts were documented in aircraft flight book. According to AMC, 1) they consider adding oil as normal service and does not normally track the amount added, 2) mechanics might include the information in the logbook but are not required to do so, and 3) pilots can be trained and authorized to add engine oil as well but are not required to do so.

Page: 1

SPECTRO

ENGINE OIL SAMPLE TEST REPORT

Phone: (817) 297-2159 - Fax: (817) 297-0088

Customer Name:	AMC-SMITHFIELD, NC	Aircraft Number:	N146DU
Bill Address 1:	3223 E SWIFT CREEK RD.	Aircraft Model:	BK117C2
Bill Address 2:		Mfg:	EC-145
City/State/Zip	SMITHFIELD, NC 27577	Engine Make:	TURBOMECA
Phone:	(919) 613-5058	Engine Model:	ARRIEL 1E2
		Serial Number:	47292
		Engine Position:	ENG1

Lab#	Sample Date	Eng Time	Oil Time	Add	Fe	Cr	Pb	Sn	Mg	Si	Cu	Ag	Ni	Al
2729	11/30/2016	2255	80	1	0.12	0.0	0	0.0	0.0	5	0.0	0.3	0.0	0.1
7	01/16/2017	2341	300	1	0.12	0.0	0	0.0	0.0	7	0.0	0.3	0.0	0.6
515	04/03/2017	2406	100	1	0.50	0.0	0	0.0	0.0	7	0.0	0.3	0.0	0.4
795	05/15/2017	2497	0	2	0.08	0.0	0	0.0	0.0	8	0.0	0.1	0.0	0.3
1194	07/07/2017	2587	253	1	0.10	0.0	0	0.0	0.0	6	0.0	0.1	0.0	0.5
1439	08/14/2017	2665	73	1	0.06	0.0	0	0.0	0.1	6	0.0	0.1	0.0	0.2

Evaluation:

NORMAL WEAR.

Figure 15: No. 1 engine SOAP Results (11/2016 - 8/2017)

Page: 1

SPECTRO

ENGINE OIL SAMPLE TEST REPORT

Phone: (817) 297-2159 - Fax: (817) 297-0088

Customer Name:	AMC-SMITHFIELD, NC	Aircraft Number:	N146DU
Bill Address 1:	3223 E SWIFT CREEK RD.	Aircraft Model:	BK117C2
Bill Address 2:		Mfg:	EC-145
City/State/Zip	SMITHFIELD, NC 27577	Engine Make:	TURBOMECA
Phone:	(919) 613-5058	Engine Model:	ARRIEL 1E2
		Serial Number:	47346
		Engine Position:	ENG2

Lab#	Sample Date	Eng Time	Oil Time	Add	Fe	Cr	Pb	Sn	Mg	Si	Cu	Ag	Ni	Al
2730	11/30/2016	2255	80	1	3.00	0.0	0	0.0	0.0	8	0.0	0.3	0.0	0.3
8	01/16/2017	2341	300	1	2.55	0.0	0	0.0	0.0	7	0.0	0.1	0.0	0.4
516	04/03/2017	2406	100	1	3.20	0.0	0	0.0	0.0	1	0.0	0.3	0.3	0.2
796	05/15/2017	2497	0	2	6.20	0.1	0	0.0	0.1	3	0.1	0.3	0.0	0.2
1195	07/07/2017	2587	253	1	6.75	0.3	0	0.0	0.0	5	0.0	0.6	0.3	0.5
1440	08/14/2017	2665	73	1	4.19	0.0	0	0.0	0.1	5	0.0	0.5	0.0	0.1

Evaluation:

NORMAL WEAR.

Figure 16: No. 2 engine SOAP Results (11/2016 - 8/2017)

AMC sent the event engine oil samples out to Spectro Inc. for analysis. **Figures 15** and **16** provide the last 6 SOAP results for both the accident engines installed in N146DU. The NTSB requested additional SOAP results for both of these engines dating prior to November 2016, which was the first and oldest result. The NTSB was informed that neither Spectro Inc. nor AMC retained the SOAP results beyond what was provided in **Figures 15** and **16**. A review of the last six SOAP test reports dating from November

2016 through August 2017[17] for both engines, ESN 47292 (No. 1) and ESN 47346 (No. 2), indicated that the No. 1 engine had what was considered normal/low levels of trace particulates and that the No. 2 engine was consistently higher in reported Fe than the No. 1 engine even though both engines had same installation date, operational flight hours and flight cycles, and the same amount of oil added. **FIGURE 17** provides a graphical representation of the SOAP sample results for both accidents engines from the data provided in **FIGURES 15** and **16**. For both engines, the note in the SOAP test report evaluation section stated, "Normal Wear"; which is inferred as referring to the last test result dated August 2017. The Fe concentration levels for the No. 2 engine oscillated up and down and ranged as low as 2.55 ppm to a high of 6.75 ppm during the reported period from November 2016-August 2017. For an incipient and progressive bearing failure, a steady and/or rapid increase in Fe concentration would be expected instead of oscillating up and down of the concentration level. Of note, between the May 2017 and the July 2017, the Fe concentration almost doubled from 3.20 ppm to 6.20 ppm: however, neither the rate of accumulation nor the cumulative Fe concentration was sufficient to trigger an alert ($7.5 \leq Fe \leq 15.0$ ppm) that would have required a maintenance action (oil sample inspection at a more frequent basis) nor did it reach the $Fe \geq 15.0$ ppm level and contamination rate $m \geq 0.5$ that would be required the engine to undergo a maintenance procedure removal according to the Turbomeca criteria (See **FIGURE 4**). **FIGURE 14** also shows criteria for Copper (Cu), Chromium (Cr), and Nickel (Ni); for both engines, the SOAP reports do not show any appreciable concentration of these elements. It should be noted that in the SOAP test reports for both engines, concentration levels for the various elements are provided but no contamination rates; Fe and Cr are considered the good markers of an impending bearing failure.

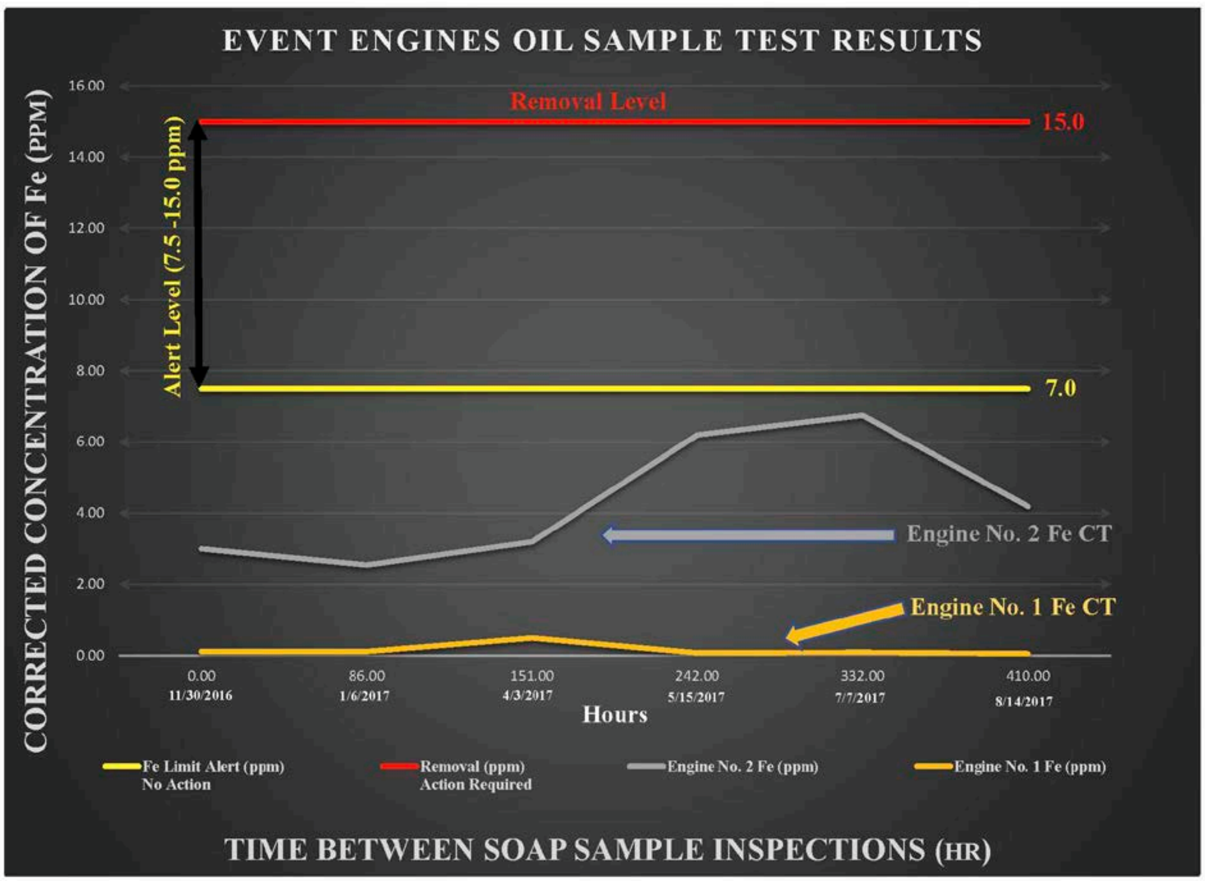

FIGURE 17: GRAPHICAL REPRESENTATION OF SOAP SAMPLE RESULTS

[17] According to AMC, no SOAP test reports preceding the November 2016 date were retained; therefore, were not available for review.

Comparing the dates of the No. 2 engine SOAP analysis (See **FIGURES 15** and **16**) with the zonal maintenance checks (See **TABLE 2**) and the aircraft flight logbook entries for the engines (See **TABLE 3**) revealed the following[18]:

1) Oil sample 1 taken on November 30, 2016. SOAP report indicates 1 quart of oil was added to each engine; could not corroborate the oil added based on the records provided.
    a. Fe concentration at 3.00 ppm and Cr concentration at 0.0 ppm
2) Oil sample 2 taken on January 16, 2017 (86 hours since last SOAP). SOAP report indicates 1 quart of oil was added to each engine; could not corroborate the oil added based on the records provided.
    a. Fe concentration decreased from 3.00 ppm to 2.55 ppm (15 % decrease) and Cr concentration unchanged
    b. After oil sample 2 was taken, oil was drained and replenished with new oil on both engines– this task is performed every 300 hour/12 months in accordance with AAIP D1040
3) Oil sample 3 taken on April 3, 2017 (65 hours since last SOAP and new oil replenishment). SOAP report indicating 1 quart of oil was added to each engine; could not corroborate the oil added based on the records provided.
    a. The Fe increased from 2.55 ppm to 3.20 ppm, an almost 25% increase in Fe concentration and Cr concentration unchanged. Engines removed and then reinstalled to comply gas generator turbine blade inspection (See **TABLE 3,** logbook number 1456173).
4) ½ quart of added to each engine (April 11, 2017), 17 hours after last SOAP and 82 hours new oil replenishment
5) Oil sample 4 taken on May 15, 2017 (91 hours since last SOAP and 156 hours since new oil replenishment). SOAP report indicates 2 quarts of oil was added to each engine; could not corroborate the oil added based on the records provided. Maintenance worksheet (**TABLE 3** dated April 11, 2017) only indicate ½ quart added to each engine between sample dates.
    a. The Fe increased from 3.20 ppm to 6.20 ppm, an almost 94% increase in Fe concentration and Cr concentration changed 0.0 ppm to 0.1 ppm.
6) Oil sample 5 taken on July 7, 2017 (90 hours since last SOAP and 246 hours since new oil replenishment). SOAP report indicates 1 quart of oil was added to each engine; could not corroborate the oil added based on the records provided.
    a. The Fe increased from 6.20 ppm to 6.75 ppm, an almost 9% increase in Fe concentration and Cr concentration increased 0.1 ppm to 0.3 ppm, an increase of 200%.

[18] Note: There is a slight variation in date between the SOAP report and the aircraft logbook (**TABLE 3**) for when the oil samples were taken. The variation in date is not significant and the difference could be due to when the task was recorded on the various reporting sheets.

b. After oil sample 5 was taken, oil was drained and replenished with new oil on both engines– this task is performed every 300 hour/12 months in accordance with AAIP D1040

7) ½ quart of added to each engine (July 20, 2017), 31 hours after last SOAP and new oil replenishment

8) Oil sample 6 was taken in August 14, 2017 and was the last oil sample taken before the accident (78 hours since last SOAP and 73 hours since new oil replenishment). SOAP reported 1 quart was added, could not corroborate the oil added based on the records provided. Flight logs only indicate ½ quart added to each engine.
   a. The Fe decreased from 6.75 ppm to 4.19 ppm, an almost 38% decrease in Fe concentration and Cr concentration dropped 0.3 ppm to 0.0 ppm.

2.3.4 Gas Generator Rear Bearing Inspection

The permeability flow check of the rear bearing TASK 72-43-10-280-801-A01 titled REAR BEARING – FREE TURBINE NOZZLE-GUIDE-VANE ASSEMBLY INSPECTION AND CHECK SPECIAL PROCEDURE provides instructions for collecting and trending the amount of oil from the rear bearing oil scavenge line to assess if it is obstructed. A **NOTE** in the rear bearing inspection instructions stated that "The inspection of the rear bearing (for clogging) is a trend monitoring task. The quantity of oil collected during successive inspection is an indicator of rear bearing clogging." However, when reviewing this inspection task requirement with AMC along with other Arriel 1 E2 operators, it was discovered that the inspection was used as a measure of engine serviceability (acceptability) and the data was not archived to be used for trending purposes.

Following the introduction of the TU 281 modification, the permeability inspection was maintained to assess whether the rear bearing chamber was sufficiently lubricated and oil scavenge duct was obstructed. Review of the EMM found no specific inspection of the oil vent duct or oil vent line (rigid steel) for clogging. According to SafranHE, the rear bearing oil scavenge line has sufficient capability to handle all the scavenge oil plus any vent air/oil mist (breather air) in the event that the oil vent line or oil vent line drain becomes clogged. A clogged rear bearing oil scavenge line reduces or prevents oil from being scavenged from the bearing compartment and returned to the oil tank. This results in several detrimental conditions such as: 1) elevated bearing temperatures from excess oil, 2) the inability to flush away containments such as dirt, metal particles, etc. that can cause premature bearing failure, 3) increase flow of oil and breather air through the vent line possibility causing carbon formation and blockage, and 4) increased bearing compartment pressure where the oil is forced past the labyrinth seals and ends up in the exhaust where is may generate smoke.

The rear bearing permeability inspection is conducted when the oil is hot, 60°C (140°F) or greater and the gas generator speed (N1) at 15% for 15 seconds. With the oil scavenge line removed, the oil is drained into a graduated cylinder until it stops. Below are the inspection criteria and additional actions:

a) If the oil quantity collected is greater than 50 milliliters (ml) or 1.7 ounces (oz), compare it with the quantity collected during the last successful inspection. If this quantity is less than found during previous inspection, collect another sample. If the result is less than 50ml (1.7 oz) then perform b) below. If two successive inspections show a difference greater than 25% then perform inspection per step c) below.

Record the inspection on the engine logbook page as well as the quantity collected and compare it with the last check.

b) If the oil quantity collected is less than 30ml (1 oz), then the oil inlet and scavenge tubes and unions are inspected for clogging.
   i. If lines or unions are clogged:
      1. Clean per TASK 72-43-00-610-801-A01 (the actual instructions do not reference the task to be performed, it merely states "clean"
      2. Examine the rear bearing for clogging
      3. Retest
      4. If less than 50ml (1.7 oz) collected, clean rear bearing – this requires removal of module M03
   ii. If tubes or unions are not clogged, clean rear bearing this requires removal of module M03
   iii. Drain oil system
   iv. Record the inspection and cleaning on the engine logbook page as well as the quantity collected
c) If the oil quantity collected is less than 50ml (1.7 oz) but greater than 30ml (1 oz), then check for carbon particles in the strainer and oil filter
   i. If particles found in strainer or oil filter, examine the oil inlet and scavenge tubes and unions of the rear bearing
      1. If tubes or unions are clogged same steps as b)i.
      2. If tubes or unions are not clogged, same as b)ii and b)iii.
   ii. If strainer and oil filter clean
      1. Examine inlet and scavenge tubes and unions for clogging [no information is provided if found clogged, assume using the same procedures for clogged tubes or unions as specified in b)i. or c)i.]
      2. Do the next inspection after 25-hours of operation to have trend.
   iii. Record the inspection and cleaning on the engine logbook page as well as the quantity collected

The EMM originally required the rear bearing inspection every 100 hours +10 hours. With the incorporation of TUs 274, 281, 283, and 284, the inspection frequency decreased to every 600 hours +50 hours. According to SafranHE, oil temperature comparison with different engine and different configurations along with endurance testing of 770 accelerated mission testing (AMT) cycles and 215 continuous hours was used to validate the change. A 750 AMT cycle and 207 continuous hours endurance test was used to validate TU 283/284; no oil coking was detected. Turbomeca decreased the inspection interval frequency progressively from 100 hours to greater than 450 hours and then to the current level of 600 hours in 2008 based on statistical analysis showing improvements. Several factors effect and encourage coke formation (See Section 2.4 COKE FORMATION); namely multiple hot engine shutdowns or multiple post shutdown with high temperature from heat soak back from other components which was not part of the 750 AMT cycle.

2.3.5 AMC Demonstration of Permeability Flow Check of the Rear Bearing

On July 25, 2018, AMC demonstrated the permeability inspection of the rear bearing oil scavenge line, reference AAIP B0302 (TASK 72-43-10-280-801-A01), with a representative of the NTSB present. This demonstration took place at the Life Star hangar adjacent to Backus Hospital in Norwich, Connecticut and the demonstration was completed as part of the routine maintenance task performed on helicopter N146HH/SN 9737, a model EC145e helicopter[19]. The Arriel 1 E2 turboshaft engines installed on N146HH were

[19] The helicopter evolved from the MBB-BK 117 C-2 and was rebranded as the Airbus Helicopters EC-145.

ESNs 47606 (No. 1) and 47607 (No. 2). Total time on the airframe and engines was 83 hours, 35 minutes. Normally the technicians would record the quantity of oil from the previous test on the task card. This was the first time this inspection was performed on the helicopter thus it established the baseline for future inspections.

The helicopter was initially positioned outside to run both engines to raise the oil temperature. The run was approximately 10 minutes and the oil temperature for both engines reached 85°C (185°F). Minimum requirement is 60°C (140°F). The helicopter was then positioned into the hangar, engine stands were put in place, and cowlings opened/removed for access.

The No. 2 (right) was tested first. The Turbomeca procedure is to first remove the oil scavenge line of the rear bearing which the technicians did (TASK 79-29-00-900-803-A01). The procedure states to put a vessel below the oil scavenge line of the rear bearing in preparation for collecting the oil that flows during the 15 second engine motoring. There is little to no room to place a vessel under the oil scavenge line union. The technicians removed the steel oil scavenge line, ensured there was no residual oil in the line and reattached one end to the union with the opposite end facing outboard, so the collection vessel could easily be put in place to collect the oil (**PHOTO 22**). The technicians explained that they had tried various methods such as attaching a length of plastic tubing to the union to reach the collection vessel, but this proved inefficient, messy and the negative effect hot oil had the tubing. In addition, the scavenge line needed to be removed for cleaning per the routine task.

The No. 2 was motored for 15 seconds and oil started to flow approximately five seconds after initial engine rotation. The collection vessel was held in place until the engine rotation spooled down after the motoring and no additional oil was flowing from the oil scavenge line. The oil scavenge line was disconnected and placed vertically above the collection vessel to ensure no residual oil remained. No additional oil remained. Approximately 145ml (4.9 oz) of oil was collected (**PHOTO 23**).

PHOTO 22: ENGINE NO. 2 FLOW TEST

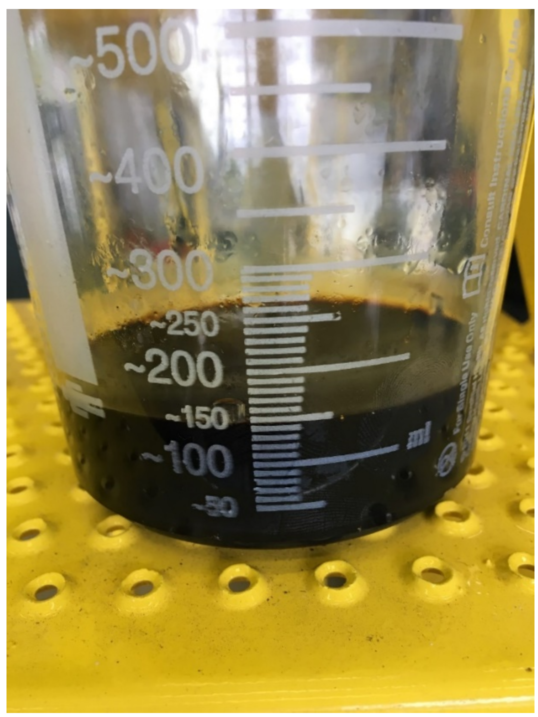

PHOTO 23: ENGINE NO. 2 TOTAL OIL COLLECTED

The procedure was then repeated on the No. 1 engine. The removal of the oil scavenge line proved to be a bit trickier on the No. 1 engine as compared to No. 2 two due to limited access. Once the oil scavenge line was disconnected, repositioned, and reconnected to the rear bearing oil scavenge line union with the open end facing outboard the engine was motored for 15 seconds. Approximately 145ml (4.9 oz) of oil was collected during the test, same as the No. 2 engine. The data was recorded on the AAIP task card and entered in the AMC Quality Management System (EtQ) for future trend monitoring.

Both engines passed the initial test (TASK 72-43-10-280-801-A01 stated that greater than 50ml of oil must be collected of no additional maintenance to be required) and other then cleaning the oil scavenge line and reinstalling, no additional steps were required for this visit. The technicians did point out the additional step-by-step procedures that would be required if the oil flow was less then 50ml but greater then 30ml or if the difference in the oil collected is greater than 25% from the previous check. The technician also explained the various scenarios, dependent on inspection findings, that would require the rear bearing to be cleaned which would result in the engine being removed to facilitate removal of the rear bearing for cleaning. Technician further explained that they could remove the engine but would have to send the engine module out for rear bearing removal and cleaning.

2.4 Coke Formation

Coke formation occurs when the temperature of the oil resides at a temperature higher than the oil stability limit for a sufficient amount of time and this is influenced by several factors from oil type, operating condition, and part geometry. As previous mentioned, the Turbomeca SL No. 1642/96/Arriel/25 recommended the use of HTS oils to reduce the formation and accumulation of coke deposits. Although some oils perform well under one set of conditions they may perform poorly under others; therefore, engine manufactures test and validate a variety of oils for use in their products as there is typically not one oil that excels in all conditions. Operational conditions such as hot engine shutdowns or post shutdown high temperature from heat soak back from other components can influence and promote coke formation; coke formation increases dramatically when oil is in contact with surfaces in exceed 300°C (572°F). Another operational influence is prolonged engine inactivity where the coke that has formed absorbed moisture that makes the coke more prone to shedding; shedding typically occurs after engine start. Although coke formation is not desirable, if it does occur, it is better that it stays there instead of shedding and migrating. Coke shedding can result in obstruction of oil filters, oil passages, and orifices downstream.

The geometry of oil lines and bearing compartments can factor into coke formation and oil obstruction. Small diameter oil passages and lines as well as changes in oil flow path direction can reduce oil flow rate which increases the dwell time the oil may reside on a hot surface thus promote coke formation. Blockage of the oil passages from either accumulation of coke or shedding of coke can result in a similar increase in oil dwell time at higher than desired temperatures; small diameters (low volume) oil passages and lines are more prone to blockage than high volume. (ExxonMobil Corporation, 2016)

Turbomeca SL No. 1642/96/Arriel/25, 2nd issue, dated May 15, 1996, titled ARRIEL 1 – All Variants Oil Coking in the Gas Generator Rear Bearing Housing was the most current version of the SL at the time of the accident (See **Attachment 3**). The SL informed operators of cases where coke was observed in the rear bearing housing either on the oil jet or in the oil scavenge orifice and the potential results such as lack of lubrication leading to bearing deterioration and particles in the oil, or inadequate oil scavenging leading to oil bypassing the labyrinth seals into the exhaust creating smoke out the tailpipe. The SL discusses methods to detect and reduce the carbon formation such as the introduction of the gas generator rear bearing permeability flow check, recommend incorporation of TU 208 EMP, recommended a new engine stabilization procedure before shutdown (30 seconds at idle speed of 70%±2% gas generator speed (N1)[20]). The SL also stated that a study was initiated to reduce oil coking by relocating of the rear bearing oil jet to an area with reduced temperatures. As a result of that study, Turbomeca issued TU 281[21] that moved the lubricating jet from the bottom end of the oil supply duct into the union at the top of the duct.

2.5 Engine Power Assurance Check

The Airbus Helicopters FM for the MBB-BK 117 C-2 calls for power check to be performed at intervals no greater than 100 flying hours or when abnormal engine function is suspected and the AMC's AAIP calls for the power check to be performed every 50 hours. The power assurance checks are performed as part of scheduled independent inspection under identifier number D0330. According to the FM Section 5 Performance Data, there are two procedures for performing the power check, one a ground check and the other for inflight. AMC performs the ground check which is intended to make certain that the engine power available is with the limits established for legal use in accordance with the performance charts. AMC has a dedicated form by which the power check data is recorded. Section 5.1.4.5 of the FM provides instructions for trending the power check data. For each engine, a trend line is established based on an average on the most recent consecutive 5 data points of operation. The maximum permissible N1 margin drop down between a single power check result and the average trend line is 1.5%. If the change is greater, abnormal function of the engine or engine instrumentation should be assumed and maintenance action in accordance with the maintenance manual is highly recommended. The N1 margin is defined as the difference between the %N1 chart limit for a given outside air temperature and pressure altitude verses %N1 and the measured N1 (chart limit N1 minus measured N1). A positive number indicates positive margin and the engine is producing more power than is needed for a given condition while a negative number indicates negative margin and the engine is producing less power than needed for a given condition.

A review of the power check data for both the right and left engines between January 2017 and the accident (September 2017) revealed positive margin for both engines at each check and that on average both engines had positive margin of about +1%N1 average with a few data points greater than 1.5% N1. For the last two power assurance checks performed before the accident, 37 and 76 hours respectively before the accident, the margin was less or equal to 1% N1.

[20] The complete engine shutdown procedure can be found in the Airbus Flight Manual (FM) MBB-BK 117 C-2 normal procedures Section 3.11.

[21] TU 281 was part of SB 292 72 0215 titled M03 Module (Gas Generator) Modification of Rear Bearing Incorporation of Modifications TU 274-281-283-284, dated May 23, 1997.

3.0 METALLUGICAL EXAMINATION RESULTS

3.1 Engine Hardware Examination at SafranHE

Various components of the No. 1 and No. 2 engine were sent to SafranHE in France for metallurgical examination. The following is a synopsis of the SafranHE report; for complete details see SafranHE reference RA 2017/238 titled N146DU Accident Investigation Findings & Analyses, dated April 19, 2019.

3.1.1 No. 1 Engine – ESN 47292 Hardware Examination

Fuel system components were examined for any anomalies or obstructions and the following were found: 1) fuel ejector found it to be free of obstructions, 2) the low pressure fuel filter (external to the fuel control) was in good condition and clean, 3) disassembly of fuel control found the HP filter was in good condition and clean (**Photo 24**), the fuel inlet strainer unobstructed (**Photo 25**), the metering needle satisfactory; no indications of an internal failure, presence of foreign objects or contamination, 4) the gears and drive shaft of high pressure fuel pump, which is internal of the fuel control, were intact and good condition (**Photo 26**), 5) the deceleration control diaphragm within the fuel control was found ruptured and pieces were brittle consistent with elastomer being exposed to high temperature, 6) the pressure differential (delta-p) diaphragm within the fuel control was found split lengthwise brittle consistent with elastomer being exposed to high temperature and the fracture surface was constituent with a rupture failure, 7) drain valve purge diaphragm exhibited delamination, tears and melting consistent with diaphragm being exposed to high temperature, and 8) all the fuel tubes and the fuel injection manifold were x-rayed and all were found to be clear with no obstructions. In summary, the only damage observed to the fuel system components were consistent with the initial impact or post-crash fire; no pre-existing failures, contaminations or obstructions were found and according to SafranHE no discrepancies were found that could explain why the engine FCU was in the CLOSED position.

Photo 24: HP Filter Clean

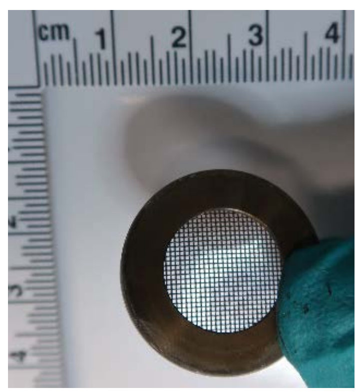

Photo 25: Fuel Inlet Strainer Clean

Photo 26: Fuel Pump Gear Undamaged

Photos Courtesy of SafranHE

With the rear bearing showing signs of black-coke like material during the examination at SafranHE in Grand Prairie, the rear bearing oil supply, scavenge, and vent lines and drains were examined for any obstructions or coke building up (**Photos 27-29**). All the lines were clean with no obstructions but a thin layer of coke was observed on intern walls of the lines; the amount of build-up was according to SafranHE within their in-service experience. The rear bearing itself was in good condition and met the material specifications. Examination of the magnetic plugs and the oil strainer found no metallic particles and were clean. The oil pump was seized so it could not be tested; however, disassembly found all the gears and drive shaft to be in good condition. All the oil supply and scavenge lines were x-rayed and no obstructions were observed.

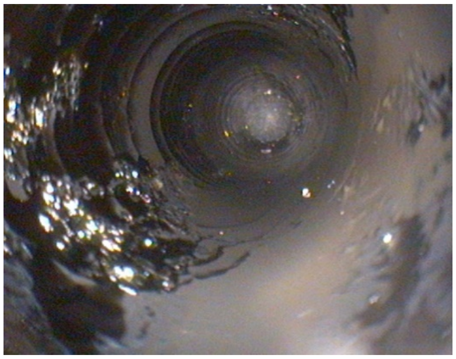

PHOTO 27: OIL SUPPLY LINE

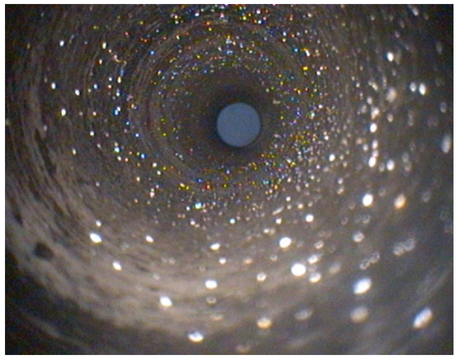

PHOTO 28: OIL SCAVENGE LINE

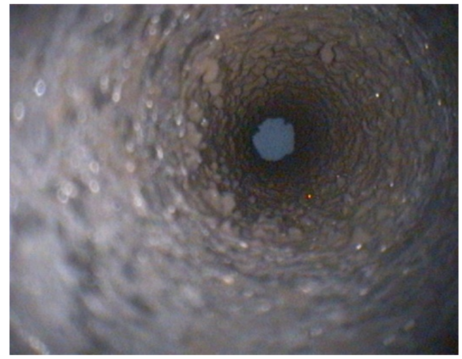

PHOTO 29: OIL VENT LINES

Examination of the gas generator and the reduction gearbox found no internal failures or anomalies. In summary, examination of the all the No. 1 engine hardware found no evidence of an internal mechanical failure or a pre-existing condition like obstruction or contamination of the oil, air, or fuel system components or that preclude the engine from operating properly.

3.1.2 No. 2 Engine – ESN 47346 Hardware Examination

During the hardware examination at SafranHE Grand Prairie, the gas generator rear bearing was seized, all the roller elements were flattened flush with the cage and lack lubrication. All other internal engine damage that was observed was consistent the failure and seizure of the gas generator rear bearing; thus, the focus was to identify contributors or causes for the rear bearing failure and any sources of oil leak paths to account of witness statements reporting smoke trailing from the helicopter (See Docket for details on the witness statements).

The oil pump was seized so it could not be functionally tested. Disassembly of the oil pump revealed that all the pressure pump gears were in good condition and intact; however, the elastomeric seals were brittle and degraded consistent with elastomers being exposed to high temperature and the gears were essentially dry. The gears on the scavenge side of the pump were also essentially dry, in good condition, the bearing surfaces exhibited circumferential scoring and the presence of debris, with the rear bearing scavenge pump gears exhibiting the most scoring. All the particles from the oil pump, gas generator rear bearing oil strainer and scavenge line, and from module M05 (reduction gearbox) were examined by performing Scanning Electron Microscopy (SEM) and Energy Dispersive X-Ray Spectroscopy (EDS)[22]. According to the SafranHE analysis,

[22] A scanning electron microscope (SEM) is an electron microscope that offer high resolution and high magnification. The SEM focuses on the surface and composition of the sample by scanning the surface of a sample with an incident electron beam. Electrons from the sample scatter creating secondary electrons typically of low energy value or the electrons from the incident beam bounce upon impact with the sample creating backscattered electrons typically of higher energy values; both of which are collected to create three-dimensional images that are black and white. In the secondary image mode, the differences in surface topography are represented by variations in gray scale intensity while in backscatter mode, the image is mapping changes in material density. Some SEMs have an energy dispersive x-ray spectroscopy (EDS) detector that captures x-rays emitted from the sample during the creation of secondary electrons. When creating secondary electrons, x-rays are emitted as electrons from the high energy outer shells fill the void left by the ejection of lower energy electrons in order to stabilize the state of the atoms. The x-rays emitted are characteristic in energy and

all the metallic components were consistent with the material of the gas generator rear bearing and the other non-metallic particles were consistent with oil or the elastomeric seals. The oil system supply and oil scavenge line were x-rayed and no obstructions were observed. The three gas generator rear bearing ducts (See **Figure 5**) that form the connection between the oil supply, scavenge and vent lines to the gas generator rear bearing chamber were visually examined and all exhibited some level of coke layer on the inner wall with oil supply and scavenge ducts exhibiting the greater amount but in all three cases the passage was clean with no obstructions. Examination of the oil restrictor, located between the oil inlet duct and the supply line, also revealed no obstructions. To help resolve the various witness reports stating that smoke was coming from the helicopter, various oil leak paths from the gas generator rear bearing were evaluated. The parts around the gas generator rear bearing, namely the internal cup plates, the power turbine nozzle guide vane assembly and the front face of the bearing chamber all appeared dry with no significant traces of oil or any appreciable oil staining indicating the presence of oil leak path.

As mentioned previously, the aft shaft exhibited contact damage to all three of the rotating labyrinth seals with the greatest amount of damage observed on the smallest seal nearest the rear bearing journal. Also observed was metal transfer on the rear bearing journal of the aft shaft. According to SafranHE, this variation in seal damage is indicative of damage that occurred during engine operation as the aft end of the gas generator continues to deflect due to the progressive failure of the rear bearing but is not indicative of high imbalance since all the seals are relatively intact.

Detailed visual examination of the rear bearing revealed the following: 1) roller elements were flattened flush with the cage was consistent with rubbing and skidding along the inner race, 2) the thickness of the recovered pieces of the inner race[23] were about ⅔ of its nominal thickness, again consistent with material loss from the roller elements skidding along the inner race and the metal transfer observed on the aft shaft bearing journal, 3) after sectioning of the bearing, the roller elements exhibited flat spots in the area of contact with the outer race that is consistent with the rollers also skidding in relationship with the outer race but only to a limited extent since the outer race remained intact and its geometry remained relatively unchanged, 4) the roller elements were not only flattened but also plastically deformed and bulged; the cage was also plastically deformed, and 5) the outer diameter of the outer race did not show any indications of movement either rotationally or longitudinally with the cage. SafranHE concluded that there were no indications of the gas generator rear bearing being misinstalled, excessive oil temperatures, excess oil, or lack of lubrication and the deformation observed was due to the elevated operating temperatures created by the roller elements skidding but could not definitively conclude the exact cause (See Section 3.1.3 No. 2 Engine – ESN 47346 Oil Analysis Result for details).

Metallurgical evaluation of the rear bearing components, roller elements, cage, and inner/outer races revealed that the bearing complied with the material composition specifications; however, the hardness values were less than specified and varied depending on the location the hardness reading was taken. The outer race, roller elements and the inner race are all made from 80DCV40[24] and the cage is made of 40NCD7[25]. According to SafranHE, at higher operating temperature the hardness of the bearing material will

wavelength of the element that emitted them, so the composition of the sample can be determined. Elements that have high atomic number will have several x-ray elemental peaks while elements that have low atomic number have few x-ray elemental peaks. The various elemental peaks represent the shell that the electrons were ejected from and the shell from which the electrons were filled.

[23] The sum total of the recovered inner race pieces was less than what would be required for an entire inner race.

[24] 80DCV40 is a bearing steel and is the similar of M50 with a composition of Carbon (C) 0.77-0.85%, Silicon (Si) 0.10-0.35%, Manganese (Mn) 0.10-0.35%, Phosphorus (P) 0.015%, Sulfur (S) 0.015%, Chromium (Cr) 3.90-4.40%, Molybdenum (Mo) 4.00-4.50%, Nickel (Ni) ≤0.15%, Copper (Cu) ≤0.20%, Tungsten (W) ≤0.25%, Vanadium (V) 0.90-1.10%, Aluminum (Al) ≤0.050%, and the remainder is Iron (Fe).

[25] 40NCD7 is a and is the equivalent to the American Iron and Steel Institute (AISI) 4340 with a composition of C 0.38-0.43%, Si 0.15-0.35%, Mn 0.65-0.85%, P and S <0.025%, Cr 0.70-0.90%, Mo 0.20-0.30%, Ni 1.65-2.00%, and the remainder is Fe.

initially drop and increase again and the hardness values observed were consistent the elevated operating temperature the bearing experienced as the roller elements skidded. A Nital etch of a cross section of the cage, roller element and outer race showed a uniform heat profile (homogenous color) for each part; however, the shoulders of the outer race where the roller element made contact were slightly darker and appeared more consistent with the roller element. According to SafranHE, this is indicative of the seized roller elements transferring heat to the outer race. The rear bearing compartment did not exhibit significant variations of color thus suggesting that the heat was not transferred further.

During the engine examination at SafranHE Grand Prairie, the inlet nose cone was wrinkled, and the axial compressor wheel and the axial compressor shaft exhibited dark blue discoloration (See **Photo 17**); the back side of the axial compressor wheel and three distinctive circumferential blue bands around the axial compressor shaft. SafranHE attributed the blue discoloration to the post-crash fire. Metallurgical evaluation of the axial compressor shaft (the shaft has a 0.1mm corrosion protective coating layer of chromium plating) and the Nos. 1 and 2 bearings found that the material conformed to the specification in chemical composition, required hardness, and microstructure indicating that the parts operated at an elevated temperature significant to alter the surface appearance but not to change the structural integrity. No circumferential or axial grooves or scoring was noted on the shaft that would indicate that the bevel gear or the bearings had translated during operation. SafranHE concluded that the bearings condition (round and intact) was due to operating at high temperature and not associated with a lack on lubrication. The oil pipes and the oil jet for the compressor's bearings were checked and found unclogged. According to SafranHE, the corresponding thermal distress noted on the axial shaft was the discoloration of the chrome plate from the heat generated from the bearings but that the heat did not penetrated beyond the protective coating based on hardness and microstructure results. It is worth noting that when the gas generator's rear bearing deteriorated, the load on the compressor's bearings increased.

3.1.3 No. 2 Engine – ESN 47346 Oil Analysis Results

Oil samples were collected from the reduction gearbox during the engine exam at the SafranHE Grand Prairie facility and those samples were evaluated by SafranHE. For clarity, the oil sample taken and tested after the accident will be referred to as the event sample/test and the samples/tests documented in **Figure 15** will be referred to as in-service sample/test. SafranHE conduct a SOAP and RULER™ test on the event oil samples similar to what was discussed in Section 2.3.3.2 Oil Analysis Requirements of this report. The SOAP analysis showed that the event Fe concentration level was 2.3 ppm which was lower than any of the in-service samples from November 2016 to August 2017 (lowest Fe was 2.55), and much lower than the last three in-service samples taken between May 2017 to August 2017 (Fe concentration level ranged from 4.19-6.20 ppm). All other element concentration levels in the event sample were low, except for Ni and Cadmium (Cd), which were 6.29 and 13.34 ppm respectively. Ni was only detected twice in the in-service oil samples at a concentration level of 0.3 ppm. Cd was not recorded on the in-service test sheets at all (See **Figures 14** and **15**) nor is it event listed in TASK 71-02-08-280-801-A01 alert/engine removal criteria listed in **Figure 11**. Ni is a constituent of all the bearing parts but is in higher concentrations in the bearing cage. However, for the bearing races and roller elements Ni may be absent entirely; according to the material specification Ni $\leq$0.15%. Cd is often used as a corrosion protective coating and is used sometimes in bearing material because it has a low coefficient of friction and good fatigue resistance properties. Cd is not a constituent of any of the bearing material in the event engine and is considered a contaminant and according to SafranHE is not a potential contributing factor to the bearing failure.

As previous mentioned the RULER™ test is used to access the quality of the oil by measuring the levels of the antioxidants remaining, the acidity of the oil and the viscosity of the oil (See Section 2.3.3.2 OIL ANALYSIS REQUIREMENTS). The results of the RULER™ test revealed that the residual antioxidants level of the event oil was 9% and according to TASK 71-02-08-280-802-A01 specifies the minimum rate of antioxidants is 70% and below that value, it is strongly recommended to change the oil. The event oil viscosity at 40℃ (104°F) was 28.8 cSt. Per Military Performance (MIL-PRF) Specification MIL-PRF 23699F, titled LUBRICATING OIL, AIRCRAFT TURBINE ENGW SYNTHETIC BASE, NATO CODE NUMBER 0-156, the viscosity requirements were given at two temperature points: 100℃ (212°F) viscosity should be between 4.9-5.4 cSt and at 40℃ (104°F) viscosity should be a minimum of 23 cSt. The acidity of oil, typically called the total acid number (TAN), for Mobil Jet II per the ExxonMobil Specification sheet on their website states that the typical sample has a TAN value of 0.03 mg KOH/g; SafranHE tested a sample new of Mobil Jet II and is measure 0.05 mg KOH/g. The TAN value is measured in the mass of potassium hydroxide (KOH) in milligrams (mg) to neutralize 1 gram (g) of the oil; hence the value of TAN is measured in mg KOH/g. TAN is a method to determine the additive depletion, acidic contamination, and oxidation of the oil and does not directly measure the rate of oxidation but merely measures the by-product of oxidation. The TAN value for the event oil was 22 mg KOH/g. SafranHE concluded that the oil was in a degraded state but could not determine how much the degradation had occurred during operation or was a function of the oil being exposed to the post-crash fire.

3.2 3-WAY UNION DECK DRAIN FITTING EVALUATION AT THE NTSB

The No. 1 engine drain fitting and the No. 2 drain fitting and oil vent drain were shipped to the NTSB Materials Laboratory in Washington DC, for examination and evaluation. The following section is a synopsis of the NTSB Materials Laboratory report; for complete details see NTSB MATERIALS LABORATORY FACTUAL REPORT NO. 18-010, dated September 21, 2018 in the public docket of this accident. To facilitate material identification of the various samples, exemplar flexible elastomer oil supply and vent line drains (See **FIGURE 5**) along with the shrink wrap jacket used to secure the drains to the 3-way union deck drain fitting ports were provided and evaluated. The four ports on the 3-way union deck fitting were identified as follows: Inlet Port 1 – Module M01 oil drain, Inlet Port 2 – oil vent from rear bearing compartment, Inlet Port 3 – oil supply line deflector, and Outlet Port 4 – attaches to the helicopter structure and is the outlet drain.

Each port of the No. 1 engine 3-way union deck fitting was visually inspected for the presence of sludge, coking deposits, or other obstructions and 0.033-inch diameter stainless steel wire was used to access the extent of the obstruction (**PHOTO 30**). The Module M01 oil drain port was sooted and was estimated that about 20% of the area was reduced. The oil supply line deflector port (**PHOTO 31**) and the rear bearing oil vent ports were 100% blocked and analysis of the black obstruction within each port found them to be consistent with material of the shrink wrap jacket. No obstructions were found in any of the ports the No. 2 engine 3-way union deck fitting and no obstructions were found in the No. 2 drain line.

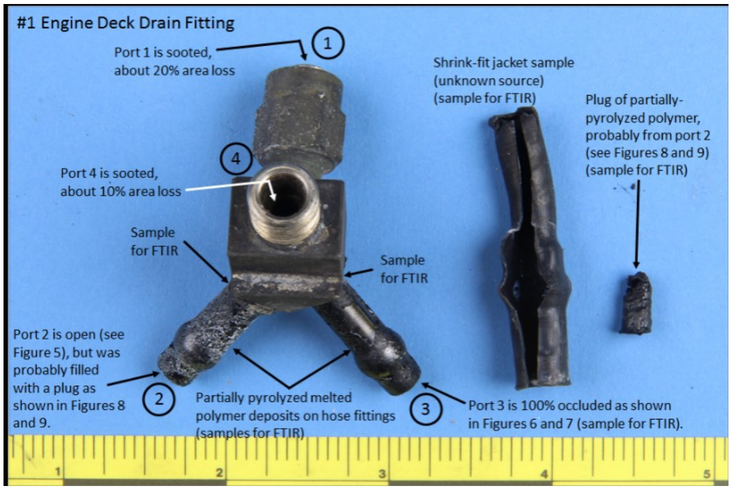

PHOTO 30: DECK FITTING PORT EXAMINATION RESULTS

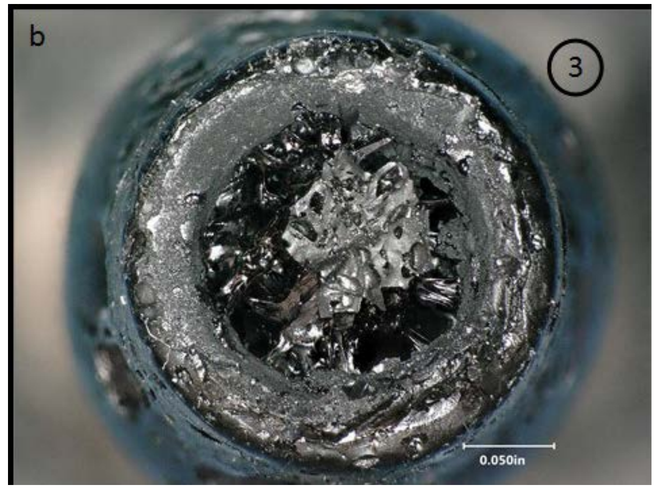

PHOTO 31: OIL SUPPLY DRAIN OBSTRUCTION

4.0 CORRECTIVE ACTIONS

On December 12, 2017, AMC revised AAIP even numbered B Zonal tasks (100 hour interval) to include detailed instructions for accomplishing the rear bearing clogging inspections on helicopters with Arriel 1 E2 engines. Instructions include the trend monitoring requirement from previous inspections that are now maintained in the quality control management system, recording current measurements and detailed cleaning instructions.

Prior to this accident, SOAP samples were taken by AMC mechanics at the various maintenance bases and shipped to the designated test facility for analysis. The SOAP analysis report would be then sent back to the maintenance base the sample was taken and the local mechanic would review the report and act, if necessary, based on the criteria in the SafranHE maintenance manual (See **FIGURE 13** for SOAP alert and removal criteria). Since the accident, AMC updated their Field Mechanic Procedures Manual (FMPM), Section 6.2.11 METAL IN OIL (MIO) EVENTS (CHIP LIGHTS), to assign the task of reviewing the SOAP analysis reports internally to an engineer to review alerts and abnormal oil reports.

5.0 ADDITIONAL INFORMATION

On October 9, 2017, AMC issued a Fleet Campaign Directive titled BASE LINE CAPTURE OF REAR BEARING CLOGGING INSPECTION, number 32-7200-FCD-2108, to perform a baseline capture of rear bearing clogging inspection for the fleet of MBB-BK 117 and EC145 helicopters. Included in the campaign was the logging of the quantity of oil measured into the EtQ quality control system for trend monitoring.

On November 16, 2017, the FAA issued SAIB SW-18-04 Subject ENGINE OIL DRAINAGE SYSTEM alerting Airbus Helicopter MBB-BK 117 C-2 helicopters owners, operators, maintainers, and repair facilities of possible blockage of the engine oil drain system based on preliminary findings from two recent NTSB investigations involving this particular helicopter model (**ATTACHMENT 5**). The first NTSB investigation involved an event that occurred on January 26, 2017 (NTSB number CEN17IA094) relating to an MBB-BK 117 C-2, registration number N911MK, in-flight fire and emergency landing in Sioux Fall, South Dakota. Examination of the engine that experienced the in-flight fire revealed coke plugging of the oil scavenge line of the gas generator rear bearing. The other NTSB investigation was based on initial findings from this event where the examination of the No. 1 engine gas generator rear bearing area exhibited a build-up of coke and the left airframe 3-way union deck drain fitting and vent line were obstructed; the No. 2 engine gas generator rear bearing area did not exhibit a build-up of coke and the right airframe 3-way union deck drain fitting and vent line were free of obstruction.[26] The SAIB recommended a repeat inspection of the 3-way union deck drain fitting and the gas generator rear bearing oil vent lines (flexible elastomer – See **FIGURE 5**) for obstructions, which may include carbon or coke deposits, every 100 hours of service operation. At the time that the SAIB was issued there were no inspection or cleaning instructions for the 3-way union deck drain fitting. As part of the inspection, the FAA requested that the results of the inspection be forwarded to the Rotorcraft Standards Branch. The SAIB contains non-regulatory information and guidance that does not meet the criteria for an AD; thus, the recommended actions are not mandatory. Not all operators chose to participate in the voluntary reporting of findings; therefore, the information gathered thus far was incomplete and the number reported inspection was too low to assess if a systemic gas generator rear bearing coking or blockage problem existed. Of the data gathered, there were reports of completely blocked or partially blocked oil drain and vent lines.

Prior to this accident and the incident involving N911MK, there was no inspection of the 3-way union deck fitting or the oil vent line drain that attached to it. On January 29, 2018, Airbus Helicopters issued Information Notice (IN) No. 3213-I-71 informing MBB-BK 117, C-1, C-2, and C-2e operators that inspection and cleaning procedures will be introduced into the next versions of the applicable MSM and AMM. The IN No. 3213-I-71 stated that the cleaning would be required every 400 flight hours and cleaning of the 3-way union deck fitting using an ultrasonic bath. The information notice included AMM TASK 71-71-00, 6-1 for inspecting the oil line drains and the 3-way union deck fitting (the task instructions call the 3-way union deck fitting the drain collector) and TASK 71-71-00, 7-1 for 3-way union deck fitting (drain collector).

On February 16, 2018, Turbomeca issued SL No. 1642 (1642/96/ARRIEL/25), 3rd issue, titled ARRIEL 1 – ALL VARIANTS OIL COKING IN THE GAS GENERATOR REAR BEARING HOUSING on February 16, 2018, to remind operators of the maintenance actions and operating procedures which are recommended in order to prevent excessive coke formation in the gas generator rear bearing and the consequences of excessive coke formation (**ATTACHMENT 6**). SL No. 1642 1642 (1642/96/ARRIEL/25) issues 1 and 2 primarily focused on inspection for gas generator rear bearing coking and ways to mitigate its formation as does issue 3 but issue 3 also included guidance and recommendations relating to the overhaul health of the oil system. Similar to SL No. 1642 issue 2, SL No. 1642 issue 3 reiterated the need to perform a 30 second stabilization time at ground idle as required in the FM, recommends the use of HTS oils to reduce the risk of coking occurrence in the gas generator rear bearing and reminds operators of the performance of the permeability test (TASK 72-43-10-280-801-A01). Issue 3 goes on to remind the operator the importance of conducting the applicable gas rear bearing (strainer and EMP) inspection and cleaning, compliance with the oil drain frequency, the user to the RULER™ test to determine the health of the oil and that the oil permeability check "..should be considered as monitoring of the trend of the quantity of oil collected during successive checks."; none of these were covered in previous issues of the SL.

Submitted by Gregory Borsari
Aviation Accident Investigator - Maintenance

Pierre Scarfo
Powerplant Lead

[26] Although there was no evidence that an obstruction in the 3-way union deck drain fitting or the oil vent line occurred or contributed to the engine failure and subsequent accident detailed in this report (N146DU), initial data from this event along with data gathered during the course into the investigation of the N911MK incident were used by the FAA to issue the SAIB SW-18-04 and to facilitate Airbus Helicopters in the development and implementation of 3-way union deck fitting inspection requirement and thus were deemed important to reference in this report.

REFERENCES

ExxonMobil Corporation2016Coking Residue and Deposits of Aviation Oil

ATTACHMENTS

1 Air Methods Air Carrier Certificate QMLA253, issued March 1, 1992
2 ESN 47292 and 47346 engine modifications incorporated by Turbomeca at the factory before delivery to AMC
3 ESN 47292 and 47346 engine logbook sheets when delivered new to Air Methods
4 Turbomeca SL No. 1642/96/Arriel/25, 2nd issue, dated May 15, 1996, titled ARRIEL 1 – ALL VARIANTS OIL COKING IN THE GAS GENERATOR REAR BEARING HOUSING
5 FAA SAIB SW-18-04, dated November 16, 2017, Subject ENGINE OIL DRAINAGE SYSTEM
6 Turbomeca SL No. 1642 (1642/96/ARRIEL/25), 3rd issue, dated February 16, 2018, titled ARRIEL 1 – ALL VARIANTS OIL COKING IN THE GAS GENERATOR REAR BEARING HOUSING