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

August 27, 2019

Vehicle Engine Multifunction Display (VEMD)

Specialist's Factual Report
By Sean Payne

1. EVENT SUMMARY

Location:	Hertford, North Carolina
Date:	September 08, 2017
Aircraft:	Eurocopter MBB BK-177 C2
Registration:	N146DU
Operator:	Air Methods Corporation
NTSB Number:	ERA17FA316

2. DETAILS OF INVESTIGATION

The National Transportation Safety Board (NTSB) Vehicle Recorder Division received the following device:

Device Manufacturer/Model:	**Thales Vehicle Engine Multifunction Display**
Serial Number:	**Unknown**

2.1. Device Description

The Thales Vehicle Engine Multifunction Display (VEMD) is a dual LCD screen display the provides a method of displaying engine and airframe information to the pilot. The device is used throughout the Airbus helicopter range of rotorcraft. The device has limited engine health logging capabilities. This device is capable of storing data in the non-volatile memory (NVM)[1].

The VEMD contains two EEPROM memory chips, one contained on each VEMD channel. There are two channels in the VEMD.

Each EEPROM contains four parts:

Part 1 contains non-changeable configuration data related the VEMD itself, the helicopter type and configuration.

Part 2 contains changeable configuration data related to the helicopter's configuration.

[1] Non-volatile memory is semiconductor memory that does not require external power for data retention.

Part 3 contains internal VEMD failure records. For these records, the EEPROM can record up to 256 failure records. The failure types are restricted to hardware component failures of the VEMD itself, software exceptions, missing input data, or invalid ARINIC information. When the VEMD records an internal failure, the following records are recorded:

- Flight Number
- The time at which the failure had been detected (time starting at the beginning of the flight)
- N1: Compressor fan speed
- N2: Combustion section speed
- DN1: Delta N1 used for FLI
- DN2: Delta N2 used for FLI
- TOT: Turbine Outside Temperature
- TRQ: Torque 1 & 2
- EOP: Engine Oil Pressure
- HYDP: Hydraulic Pressure
- XMSNOP: Principal Gear Box Oil pressure
- EOT: Engine Oil Temperature
- FLI: First Limit Indicator
- IAS: Indicated Air Speed
- P0: Static Pressure
- OAT: Outside Air Temperature
- GC: Generator Current (Amperes)
- AV: Aircraft Voltage (Volts),
- BC: Battery Current (Amperes)
- FF: Fuel Flow for Engines 1 & 2
- FFT: Fuel Flow Temperature for Engines 1 & 2

Part 4 contains flight records. The EEPROM is able to record up to 32 flight records. The following records are recorded:

- Flight Number:
    - At Each Engine start when the N1 reaches a certain RPM value the Flight Number is incremented and stored in the EEPROM.
- Flight Duration
- Cumulative Flight time
- Failure Flag
- Over-limit Flag : In case of Over-limit Flag is True, for the EC145/BK117 VEMD records only the Mast Moment.
- FCDS Failure Flag
- AFCS Failure Flag
- Power-up In Flight
- Mast Moment additional information:
    - Over-limit excess Maximum 1
    - Over-limit excess Maximum 2

- Over-limit excess Maximum 3,
- Over-limit excess counter 1
- Over-limit excess counter 2
- Over-limit excess counter 3
- Cumulative Mast Moment Over-limit excess counter

2.2. Device Condition & Data Recovery

Upon arrival at the Vehicle Recorder Laboratory, an examination revealed the unit had sustained both impact and fire damage. The device is shown as received in figure 1. The device was later opened and two separate components of the device were segregated. The two separate components are referred to as "lanes" and the device has the ability to function on either "lane" should a failure occur[2]. Figure 2 shows the "dual lane" characteristic of the VEMD after being opened.

Figure 1. Photo of damaged unit with three other instruments still attached.

[2] There is additional criteria as to when or whether the device function on each lane, the extent of which is not covered in the context of this report.

Figure 2. Photo of each lane of the VEMD after being removed and segregated.

In this device, data is recorded on an Atmel AT28HC256 NVM chip. Each lane contains an Atmel AT28HC256 chip. The device's internal boards were removed and the NVM chips were identified. The internal board and respective NVM, circled in red, are shown in figure 3.

Figure 3. Photo of the unit's two internal boards after removal. The NVM chip is circled in red.

The NVM chips were removed and inspected. Figures 4 through 7 show the front and back of both NVM chips. One chip was labeled "A" and the other chip was labeled "B.

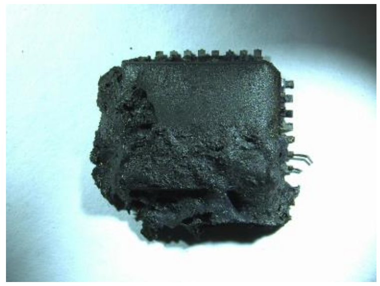

Figure 3. Front of Chip "A."

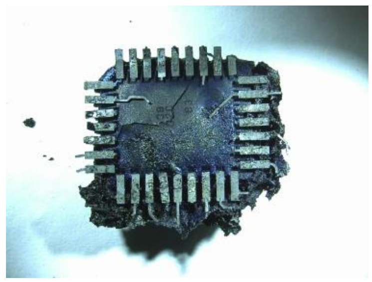

Figure 4. Back of Chip "A."

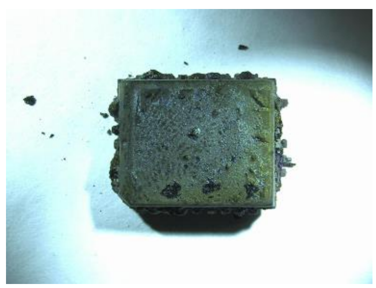

Figure 5. Front of Chip "B."

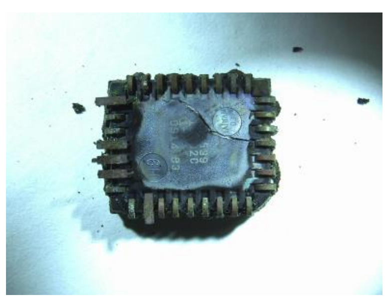

Figure 6. Back of Chip "B."

Both chips A and B were sent to The Small Scale Systems Integration and Packaging Center (S3IP) at SUNY Binghamton University. The results of the evaluation are attached to this report as attachment 1.

S3IP performed detailed visual, x-ray inspection and discussed acoustic micrscopy on the two chips.

Visual inspection by S3IP revealed that both chips were burnt with "severe thermal degradation of the mold." The molding damage potentially exposed the chip's lead frame. The visual inspection found that the contact pins on both chips were also severely damaged.

From the report, x-ray inspection revealed the following:

> "Both packages have a single die with wire bonds along its two edges. There is found severe internal damage to the mold compound with voids/air cavities and delaminations found in both packages. X-ray images reveal that there is also possible detachment of the mold from the die top surface in both packages.
>
> Module A: The die is lifted-off and separated from the die-paddle. As a result, several wire bonds are detached from the Cu leads.
>
> Module B: It is not as badly damaged as part A but it also has at least one wire bond detached from the lead frame."3

Additional details from the x-ray inspection revealed the following:

- Both chip A & B's die appeared intact and without cracks.
- Both chip A & B contained mold damage at the die paddle interface with voiding
- Chip A exhibited wire bond lifting, Chip B exhibited potential wire bond lifting.

X-ray microscopy is typically ineffective at evaluation the condition of the chip's silicon die, and as such, acoustic microscopy is employed. Acoustic microscopy requires that the chip's encapsulant be smooth such that acoustic waves can penetrate from the mold's surface and reflect off the chip's silicon die without material interference. The S3IP noted that each chip's encapsulant was too burned to perform acoustic microscopy and thus a conclusive condition of each chip's die could not be performed.

The NTSB determined that the accident chips would have to be further evaluated in order to understand the likelihood of data recovery. It was determined that the encapsulation material would have to be removed, so the chips' silicon dies could be examined further and possibly transplanted to a surrogate device for read out.

Throughout the summer of 2018 and into the spring of the 2019, the NTSB Vehicle Recorder Laboratory undertook decapsulation experiments on exemplar Atmel AT28HC256 chips. The goal of the decapsulation experiment was to develop a way to expose the silicon die of each chip without damaging the silicon die itself. Additionally, the NTSB studied the ability of the now exposed die's to retain data after being exposed to atmosphere. 25 exemplar Atmel AT28HC256 chips were purchased for experimentation.

A RapidEtch decapsulation machine was utilized for chemical decapsulation experiments. The RapidEtch machine creates a vacuum mating surface between the chip's encapsulant surface and an acid spray nozzle. As such, the vacuum mating surface requires that the chip's encapsulation surface be smooth in order to retain a vacuum. The etching machine heats the acid to a desired temperature and has the ability to dilute the acid etch solution. Various dilutions of nitric acid (HNO3), temperatures and exposure times were tested. An optimal dilution, temperature and exposure time was determined. Additionally, up to a year after decapsulation, the die's exposure to atmosphere did not seem to impact the chip's ability to retain data.

Using information gained from the decapsulation experiment with the RapidEtch machine, the accident chip's were then attempted to be chemical decapsulated. When applied to the accident chips, a vacuum mating surface could not be formed. The RapidEtch machine was still utilized, although conditions from the decapsulation experiment could no longer be guaranteed. In short, the optimal determined decapsulation settings had no effect on the accident chips. Increased temperature solutions and purities were utilized, all resulting in a minimal decapsulation effectiveness.

The accident chip's were then attempted to be decapsulated using a manual heating process and a manual acid exposure process. To control the flow of acid, a pocket, roughly the size of the package's die was milled in the surface of the accident chips which would serve as a pool to hold the decapsulation acid. A nitric acid solution was then placed in the pool and the accident chips were then transferred to a hot plate heating surface. Decapsulation was observed, however, the attempt was still ineffective at exposing the accident chip dies.

In a discussion with other academics as well as the French BEA, it was determined that heat applied to the accident chips as part of the post fire crash changed the material properties of the encapsulation mold material. A stronger acid could be utilized to expose the chip's die, however, there existed the possibility that the stronger acid would also damage the chip's die, thus rendering data recovery impossible.

The chip A was then determined to be a candidate for mechanical decapsulation using a micro pneumatic tool and a stereoscope. Chip A was successfully mechanically decapsulated, with possible damage to the die existing as a result of the mechanical process. Figure 7 is a photo of chip A after mechanical decapsulation. The yellow arrows point to areas where bond wires have been found removed from the chip's die.

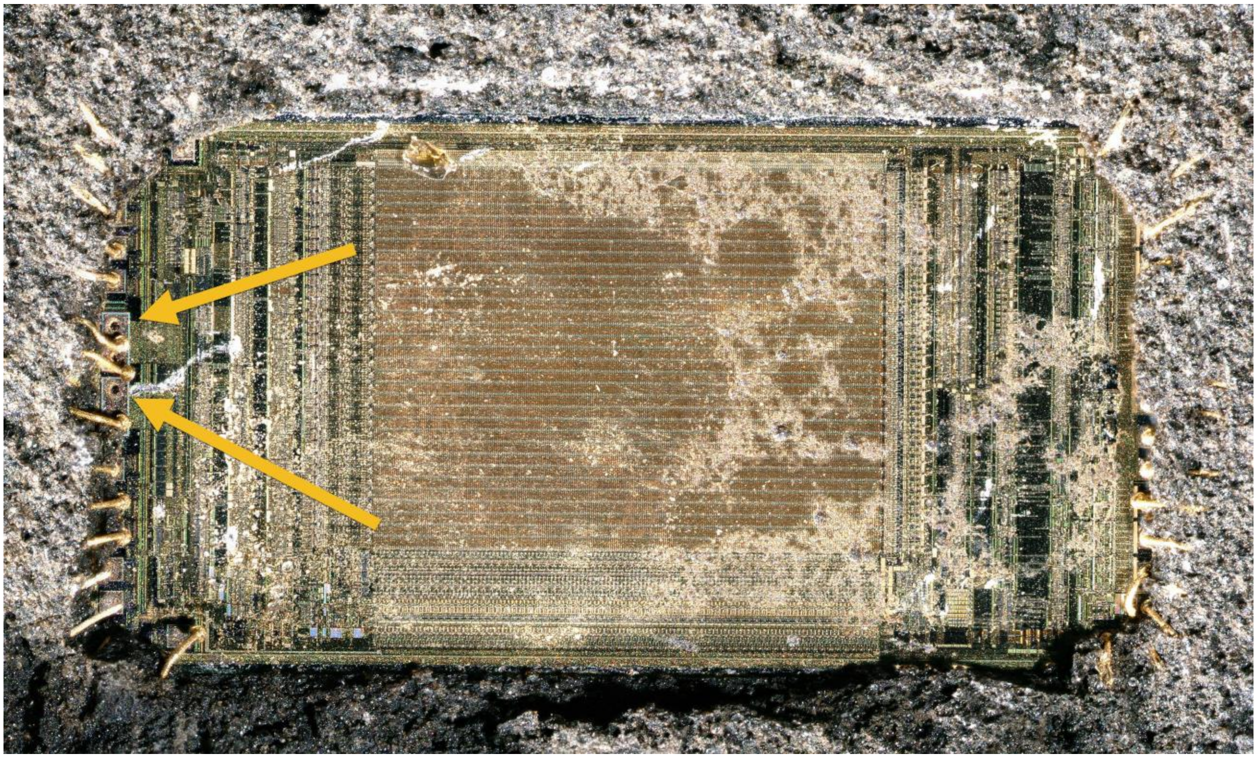

Figure 7. Chip A after having been mechanically decapsulated.

All information obtained from this exercise, including S3IP's report, were then forwarded to the Department of Defense's Cyber Crime Center (DC3). The DC3 discussed a recovery attempt of a Atmel AT28HC256 from a military accident that had been exposed to a high temperature jet fuel (JP-5) fire. As a result, the DC3 conducted extensive thermal testing of the Atmel AT28HC256 chip. The DC3 found that data lose due to thermal activation began at 275 – 300 degrees Celsius. Additionally, DC3 tested Atmel AT28HC256 chips in thermal exposure scenarios to a limit of 400 degrees Celsius for 30 minutes, which simulated the "gentlest" environment chip's exposed to a JP-5 fueled fire would have experienced. DC3 found that x-ray examination of the heated chips revealed no obvious defects, however, when attempted to be read out, the chip's exhibited an open-circuit response. The information from DC3 went on to indicate, the following:

> "It was concluded that the temperatures had not only exceeded the critical threshold where thermal activation caused the release of the electrons associated with data storage, but that advanced polymer decomposition and possibly even dopant diffusion was also beginning to occur. No further testing or recovery attempts were made."

In consultation with other members of the NTSB's Vehicle Recorder laboratory and the Investigator-In-Charge, no further recovery efforts were pursued. The extent of the damage to the NVM chip's precluded normal recovery procedures and additional attempts were unsuccessful in yielding usable data.

2.3. Data Description

No data was recovered from the device.