MH370 – IGARI-MEKAR: the leg flown with the sole power of the RAT

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Executive Summary

Understanding what happened during the leg starting after the U-turn (after IGARI) and finishing by the ping #1 (Arc-1) is key to determine the aircraft status before the possible determination of the full trajectory. In this leg there are quite a few sources of information which have already been extensively analysed but not along the perspective of this study tidily combining electrical power considerations with Inmarsat data detailed analysis.

Starting by the overall conclusion first, we are of the opinion that for the leg after the U-turn (after IGARI) until the ping #1 (Arc-1), the scenario of a manual piloting with the RAT electrical power alone is compatible with the sequence of events and technical elements analysed in this report.

The probable scenario from IGARI to ping #1 (Arc-1) is:

a) After overflying IGARI, the transponder was switched to standby manually

b) A sharp U-Turn was performed also manually

c) Shortly after the U-Turn back to Malaysia, the main sources of electrical power were disabled (IDG, Backup generators and the APU)

d) During the interim, the main battery supplied the necessary power

e) The RAT deployed and then provided the necessary standby electrical power after the power break.

f) The aircraft was piloted manually possibly using intermediate VOR radials. This is recognised as a possible procedure by pilots.

g) Around 18h23 UTC the IDG were switched back on. This powered up the SDU, the ACARS and the non-critical functions of the IFE. The electrical power was re-established at about the same time of exiting the Western Hill radar coverage. This was not a coincidence. This is convincingly justified by the hijacking modus operandi as described in [1].

h) Then a Reset Data Link command was executed via the Master Manager page before the SDU could become operational. This switched the ACARS media to the default central VHF in data mode. In addition, this reset the company and flight information to default values and thus making the Flight ID not available anymore.

i) Quickly afterwards, the ACARS was switched to "Auto Message Off" to block any message transmission as the Reset Data Link above had put it on.

j) The SDU reconnected to the Inmarsat network recognised only by the AES ID transmitted in all messages with no exception. The Log-on request could not include the missing flight ID.

This kept the aircraft as most anonymous as possible… successfully …

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The originality of the study relies in the comparison of the timings and events between MH371 service preceding the MH370 service on March 7 UTC in light with the electrical power status. It shows that the presence, but more importantly the absence of data brings valuable information for interpreting the status of the systems.

1. The absence of ACARS media advisory message at 12:50 UTC after the first Log-on #31 for MH370 service shows that ACARS was functioning but that the SATCOM was not the default media. ACARS tested the satellite link only to verify that the satellite media was available. This provides additional substance to the interpretation that this Log-on #31 is the result of a power-up of the SDU coming from an aircraft power-up. This is also very much in line with an ACARS system starting up and normally setting the default media to central VHF (data mode) with no manual intervention to select the SATCOM and thus without the need to proceed with the media advisory message.

   Correlating this with the already identified elements from other published analyses like the use of low gain antenna for example increases the probability of a power-up of the SDU at that time.

2. At 12:50 UTC, the very long time taken by the IFE to transmit its requests for log-on compared to the warm IFE requests during MH371 service and the one a little bit later during the MH370 service shows that it performed other tasks during this time. Considering that the timing of the same requests from the IFE at 18:25 UTC in flight is 50% shorter, one could conclude that - as during MH371 where no test in flight took place - this behaviour is due to self tests at start up time on the ground and in flight (the proportion for the latter is indeed coherent to the usual reported timings by pilots).
   This brings additional coherence to consider that at 12h50 UTC and 18h25 UTC, the SDU was changing status from power-off to power-up.

3. At 18h25 UTC, the absence of "resume" requests but the direct presence of a Log-on from the IFE indicates that the system recognised ab initio that the logical channels FE & FF were known to be released which should not have been the case normally for a log-on via the same satellite without a prior log-off request. A power-up of both left and right AC buses powering the IFE is the most logical interpretation of this behaviour.

4. This is an additional element to believe that the aircraft was powered by the RAT only as both AC buses were off. This, in addition to blocking any electromagnetic emission and communication in particular, is very well in the spirit of making the aircraft untraceable and in line with the modus operandi described in [1] for this leg.

5. At 18h25 UTC, Log-on #35 includes a single LIDU Log-on request showing that the SDU was <u>not</u> receiving the flight information data via the ARINC 429 bus. A Data Link Reset in flight had been performed before it could log-on. Doing so not only erases the flight ID but also selects the default media to be the central VHF in data mode.

6. At 18h25 UTC, the absence of the ACARS messages series indicates that after its power-up the ACARS was disabled immediately and put on "Auto Message Off" blocking it from sending any message anymore.

7. At 00h19 UTC, an end-of-flight scenario as described in [1] shows that - just after having been powered-up - the SDU has been powered-off again at the very moment of the end of the completion of its log-on. This could explain the abnormal BFO of the last AES R-Channel transmission at 00:19:37 UTC.

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1 Introduction

A lot of studies have been performed to understand why and how the Satellite Communication system (SATCOM) which includes the Satellite Data Unit (SDU) did not transmit the planned ACARS messages at 17h37 UTC and why from 18h03 to 18h06 UTC the ACARS messages from the ground to the cockpit printer did not go through.

This study takes a new perspective in considering that an experimented person in command (PIC), most probably the current captain, took the control of the aircraft and had to switch off the electrical power to make the aircraft "electromagnetically" invisible in addition to the reasons coming to the modus operandi of the hijacking itself as described in [1].

This study was performed via a deep analysis of the electrical system of the aircraft and of the Inmarsat signal units log scrutinised at bit level as well as operational procedures including those concerning the data link in particular.

2 Objective

The aim of this document is to analyse in details a simple realistic scenario for the management of the electrical power by a skilled PIC. It will be demonstrated that an IGARI-MEKAR leg flown with the RAT as the quasi-sole means of electrical power is the best scenario fitting the available data on the flight. The scope of this study considers the portion of the leg after the U-Turn performed manually most likely.

3 RAT deployment

After manually turning the Mode S transponder knob to the standby position at around 17h20 UTC, the Malaysian military radar shows radar echoes of MH370 making a constant left turn to heading 273° back to Malaysia with subsequent variations between 8° to 20° as reported in the Safety Investigation Report [12]. It finally oscillated around heading 231° which is the radial 060 towards VOR Penang.

Between this time and 17:37 UTC, the due time of the next ACARS including the Engine Health Monitoring data (EHM), most likely the SATCOM lost power. As discussed earlier in this report, only scenario 2 - flight with the power from the RAT only - will be considered here as it is strongly supported a-posteriori by the occurrence of a subsequent power switch back on (cf. key event 10 in the main report) around 18:23:00 UTC.

Scenario 2 consists of disconnecting <u>all</u> electrical generators, i.e. the two main generators (IDG), the two backup generators and the auxiliary generator (APU), via the overhead panel switches and possibly isolating both electrical transfer buses. These switches are the generator control switches (GCS), the backup generator switches (BCS) and the auxiliary power breaker (APB) on the P5 overhead panel.

This voluntary manual power, a kind of "outage", in flight would have triggered the deployment of the RAM Air Turbine (RAT), which provides the minimum electrical power – called standby power – and the hydraulic power necessary for flying the aircraft[3].

Between the "switch off" time and the establishment of the full power of the RAT, there is a power break as described in the maintenance manual. This is due to the swap between different sources of alternative current (AC) when it happens in flight. During this power break, which is documented to take several minutes, the main battery acts as the main generator via the hot battery bus. Consequently, a significant discharge of the battery occurred during this power break.

[3] *On 20th Dec. 2018, LA8084 flight from Sao Paulo to London landed at Belo Horizonte (distance ~90Nm) powered by the RAT only*

An important aspect to keep in mind is that the RAT does not charge the main battery - rated 47 Amps.hour. The only possible source of power driving the main battery charger in flight is the right main AC bus, which was actually off at this point in time. Subsequently, during this interim moment, the battery acted as a direct current generator ensuring the minimum electrical power in particular to the captain flight instruments. It continued to be available as a power supply to the hot battery bus in parallel with the transformer-rectifying unit (TRU C1) powered by the RAT when it became fully functional.

In this current configuration, the engines were still fully operational providing normal hydraulic power on one hand and backup electrical power to the flight control surfaces thanks to the permanent magnetic generators (PMGs) which cannot be disconnected on the other hand. These are directly connected to the power supply assemblies (PSA). The PMGs would provide the necessary direct current power to control the aircraft if necessary. Subsequently, even with the small RAT power, the PIC did not suffer any loss of control and could continuously control the aircraft normally.

The RAT wind-mill generator does not supply power to the alternative current left bus which feeds the SATCOM equipment nor it does to the right AC bus. Thus from the power break onwards the SATCOM suffered a sudden loss of power explaining the absence of Log-Off request from the airborne earth station (AES). As explained in [2] “Definition of underwater search areas, updated Dec 2015” of the ATSB, losing power for the SATCOM would come from losing left bus power (either de-activation of left IDG, left Backup generator or loss of AC power requiring an APU auto-start), which is indeed the case in this scenario. This is also the case for the IFE which is mainly powered by the two AC buses.

Given the information above and considering the speed of the aircraft, we estimate that the power was switched off between the end of the turn before the re-entry into FIR Singapore and BASIR waypoint, as described in Figure 2.

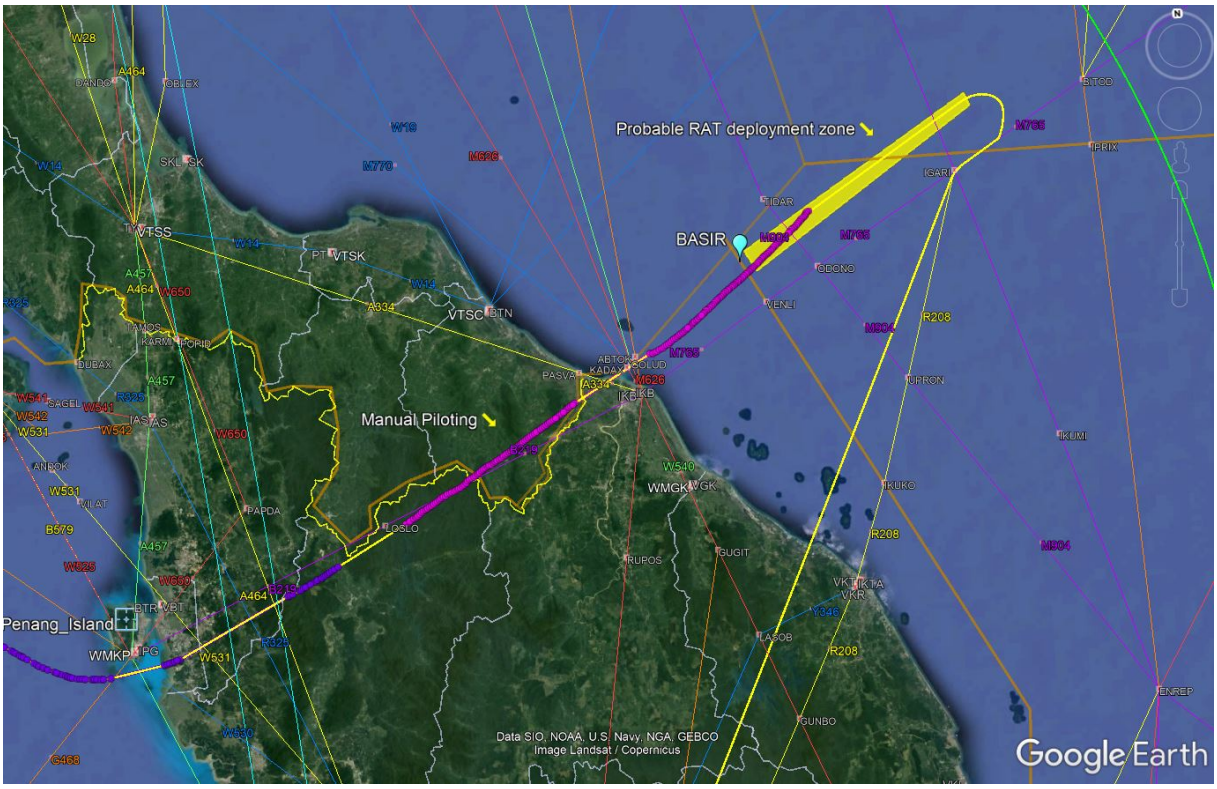

Figure 1: Probable location of the deployment of the RAT after the electrical power switch off

Under the RAT regime the Auto-Pilot (A/P) functions were not available. Nevertheless, some FMS functionalities were most probably still available, such as the use and display of waypoints on the navigation display screen using them as guiding targets during the manual piloting induced by such a situation. But considering a pilot operational perspective the characteristics of the radar blips are more in accordance with navigating around a VOR/DME radial towards Penang in order to stay above the border between Thailand and Malaysia. The only available radio navigation at that time was the left VOR.

Therefore, our opinion is that the RAT was deployed once the aircraft had been stabilised on a quasi-direct route to Kota Bharu. This manually flown leg would have lasted until the electrical power was re-established close to MEKAR waypoint. After this, auto-pilot (A/P) LNAV and VNAV functionalities would have become available again, allowing the control of the flight via waypoints with the A/P RNAV precision as in a normal flight.

An additional element detailed in [1], is that the speed variations of the aircraft shows that the automatic speed regulation was not controlling the throttles which appear to have stayed still in position when considering the different detected accelerations. No auto-throttle means no main electrical power. This brings an additional element to consider the RAT deployment.

4 SATCOM

This section aims to study the SITA logs of Inmarsat data made publicly available by V. Iannello in [3]. This file reports the hexadecimal content of the bursts of data – called signalling units (SU) – exchanged between the aircraft and the ground. A burst (Initial SU) followed or not by several bursts (Subsequent SU) of data constitutes the messages and is coded according to the ICAO specifications for satellite communication services [4]. During the study the term LIDU (link interface data unit) will also be used in place of SU to be coherent with the ICAO specifications.

A detailed analysis one by one of all Initial Signal Unit/Subsequent Signal Units (ISU/SSU) was performed to isolate each category of messages and their timing. In particular, care was taken to verify the numbering loop sequences used by Inmarsat and by ACARS to tag all messages inherent to their protocol to avoid any loss and its subsequent recovery procedure if needed.

4.1 Inmarsat messages sequential numbering schemes

The types of incremental loop numbering or sequencing are specific to the originator of the message: numerical on the AES side and both alphabetical and numerical on the groundside. Some are coded in decimal, octal or hexadecimal. Additionally, specific numbering schemes were used to sequentially tag ACARS specific messages in using chains of characters. These numbering schemes are layer dependent i.e. sub-network, AES/GES management, circuit-mode services and physical layer in accordance with the OSI system architecture. The behaviour of these looping incremental sequences brings a new perspective for extracting valuable information from the different systems behaviour.

A typical example is at burst level: except for the user data acknowledgement bursts which are unambiguous, there is always an octet providing the precedence level of the burst in its highest four bits and its numerical order in the lowest four bits with a hexadecimal repeating incremental counter.

We will not repeat what was discussed at length in V. Iannello's blog [5] but we will complement it. We will identify the completeness of the numbering sequences as well as the similarities and differences between the log-on requests made when the aircraft was in MH371 service, on the tarmac prior its dispatch for MH370 service, when it logged-on again, but in flight, at 18h25:27UTC and when it logged-on a third time at 00h19UTC. The reading will be made with respect to the possible electrical power situation and the most probable actions from the PIC.

4.2 Some features of the Inmarsat Classic Aero system

This section includes basically citations of the reference ICAO document [4].

The Classic Aero system utilizes the 24-bit ICAO technical address of the aircraft for addressing purposes. Inmarsat and MTSAT operations refer to this as the AES identifier ("AES id"), and Inmarsat assigns the unique address to every AES commissioned for operation in the Classic Aero system. It is thus important to note that the flight information is not mandatory for the communications to work.

When an AES needs to change its log-on GES, satellite or spot beam, the AES and GES follow the handover procedure described here. Log off is by user command, as part of normal operational procedures; the AES does not log off if handover is initiated as a result of P-channel loss or degradation.

AMSS protocols are defined in terms of the OSI layered reference model. The functional requirements of the link layer for P and R channels to transfer user data and signalling between the AES and the GES covers interfacing with:

a) the subnetwork layer;

b) the AES/GES management;

c) the circuit-mode services;

d) the physical layer.

The link interface data unit (LIDU) shall be the total information unit transferred across the interface between the link service user and the link layer in a single interaction.

The network layer transmits satellite sub-network protocol data units (SSNPDUs) to the user networks and receives them in return. It passes the SSNPDUs to and from the link layer in the form of LIDUs. These data units are broken down into fixed units — called signal units (SUs) — to fit into the specific structure of the satellite link channels. LIDUs comprise "real" data (link service data units) and control information (link interface control units).

The R-Channel transmits only short signal units because upon receipt of an LIDU containing an LSDU exceeding 33 octets, the AES shall route the LIDU to the T-channel protocol.

Packet data performances are based on the definitions in ISO 8348 (first edition).

The protocol between the ISO 8208 DCE and the ISO 8208 DTE shall comply with the ISO 8208 second edition. The ISO protocol equivalent to X.25, ISO 8208, is compatible with X.25, but additionally includes provision for two X.25 DTEs to be directly connected to each other with no network in between.

4.3 Detailed analysis of the LIDUs and SUs

The available data provided in [5] have been analysed. They report that the Link Interface Data Units (LIDU) exchanged by the AES and the GESs between 00:51:09 UTC on March 7 and 01:16:15 UTC on the 8th of March. They concerned two flights serviced by 9M-MRO, MH371 and MH370 on 7 March UTC.

Nevertheless, the "AES process" data logs information earlier from March 5 from 03:06:33 UTC onwards. It allows to evaluate the probable power-on of the SDU on March 6. The AES process logs report two log-on verification failures on March 6 until 14:27:14 UTC. Thus, it is most probable that the following Log-on request at 15:02:03 UTC on March 6 is the last SDU power-on before the next aircraft service when it was in Kuala Lumpur ready to depart for the previous MH370 flight (on March 6) preceding MH371 on March 7. This is somehow a situation very similar to what is reported before MH370 service in Kuala Lumpur on March 7 between 09:01:59 UTC and 12:50:19 UTC where a logon verification failed. Thus, on March 7, the time tag 12:50:19 UTC is the time for the most probable last SDU power-up before MH370 service. This means that the aircraft had not been power-

off after leaving Kuala Lumpur on March 6 i.e. the SDU was continuously powered during its stopover in Beijing. Unfortunately, no related LIDU information is available before 00:51:09 UTC for analysing the actual SDU status.

Focusing on data which is available between 00:51:09 UTC on March 7 and 01:16:15 UTC on March 8, one can see that 36 Log-on requests have been sent by the AES and recognised as such by the network. For the details, please refer to Table 7: Full set of Log-on LIDUs from 00h51:59UTC to 00h19:37 UTC of Appendix 1 in this report. One extra attempt between requests #17 and #18 was sent at 04:00:59 UTC but the LIDU (starting by 0x2F) was not received by the ground. The most probable reason for this is that it collided with another packet on the same channel POR-R600-0-36D6 which subsequently was not used.

4.3.1 MH371 service

MH371 flight phases have been delineated by the following milestones: Out of gate at 01:01:48 UTC in Beijing, take-off at 01:34:16 UTC, landing in Kuala Lumpur at 07:28:28 UTC and at the gate at 07:37:32 UTC. They are well reported in the ISUs log file. One can consider that MH371 service was terminated after the last message sent by the AES at 08:02:27 and before the failure to respond to the next Log-on interrogation at 09:012:18 UTC.

In total 30 Log-on requests have been initiated by the AES during this service as from 00:51:09 UTC. This large number is due to the (poor) quality of the link with the satellites as the aircraft flew close to the overlapping boundaries of the coverage by IOR and POR satellites. The SDU switched between these two satellites almost back and forth each time the quality dropped hoping to get a better link with the other one as specified in [4]. Amongst the 30 Log-on requests only 27 completed successfully.

A typical completed Log-on sequence as described in the Manual for Aeronautical Mobile Sat AMS preliminary version [6] is illustrated in Table 2. Two types of such sequences are possible: those of Type 1 including an unique LIDU with the header 0x**1F** when no flight information is available to the SDU and those of Type 2 with two successive LIDUs including the header 0x**2F** and 0x3F respectively when flight information is available and received by the SDU via the ARINC 429 bus (illustrated in the table).

Important note: The evidence of the availability of the flight information via the ARINC 429 bus is given by the Log-on request of Type 2 and not by the subsequent LIDUs transmitted by the IFE or the ACARS.

Table 1: Typical type 2 Successful Log-on Sequence via POR satellite when flight information is available

Time UTC	*Channel*	*GES signal**	*LIDU*	*LIDU Type*	*Comment*
00:51:09	POR-R600-0-36C4	Rx	[2F D0 10 75 00 8F 85…… F8] 0x10 - Log-on Request (ISU)/Log-on Flight Information (SSU)	10	Type 2 Initial Request part I (starts with 0x2F because flight information is available, it would start by 0x1F otherwise)
00:51:10	POR-R600-0-36C4	Rx	[3F D0 10 75 00 8F 85 …… 53] 0x10 - Log-on Request (ISU)/Log-on Flight Information (SSU)	10	Type 2 Initial Request part II starting with 0x3F and sent only if preceded by a LIDU 0x2F *(i.e. only if flight information is available)*
00:51:11	POR-P600-0-3700	Tx	0x11 - Log-on Confirm	11	GES confirmation
00:51:11	POR-P600-0-3700	Tx	0x40 - P-/R-Channel Control (ISU)	40	Packet Channels assignation
00:51:12	POR-P600-0-3700	Tx	Subsequent Signalling Unit		*Cont.*
00:51:12	POR-P600-0-3700	Tx	0x41 - T-Channel Control (ISU)	41	TDMA Channels assignation
00:51:13	POR-P600-0-3700	Tx	Subsequent Signalling Unit		*Cont.*
00:51:16	POR-R1200-0-36B9	Rx	0x15 - Log-on/Log-off Acknowledge	15	AES Log-On Acknowledge
00:51:17	POR-P10500-0-385C	Tx	0x15 - Log-on/Log-off Acknowledge	15	GES Log-On Acknowledge

** Tx = Transmitted from GES to AES / Rx= Transmitted from AES to GES (Received)*

For MH371 service, all the 30 documented successful requests were of type 2. This means that the SDU was receiving or had received properly the flight identifier via the appropriate ARINC 429 bus. During this documented service period no power-off occurred being it in the SDU or in the aircraft. The first burst documented in the log file data is the last Log-on request made about 10 min before the "Out of the Gate" ACARS message called OOOI. This short time interval – the OOOI message was sent at 01:01:47 UTC - shows that the aircraft was ready and fully powered at that time because it would not be possible to be ready for leaving the gate within 10 min after a power break. Thus, there is no way to analyse an MH371 power up period of the SATCOM as, unfortunately, Log-On #1 is not the first Log-on after a power-up sequence.

Nevertheless, some statistics of the timing of some important LIDUs during this flight are worth considering for a later comparison with the MH370 service data.

4.3.1.1 Timing of the ACARS and IFE signal units

The log file shows that when a change of satellite occurs (handover) and few seconds after completing the Log-on sequence like the one illustrated in Table 2, the aircraft ACARS systematically tests the availability of the satellite link via a LIDU of the type "Link Test Q0x" (x being a sequential loop counter). Few seconds later it sends another LIDU – an ACARS Media Advisory SAx- generated when a link status changes and sent over any other media link that is available (here it is the new satellite). This is because the crew, probably via the Communication Master Manager page, had previously selected the SATCOM.

When the AES logs in succession to the same satellite again (i.e. no handover), the series of messages Q0x/SAx does not occur, instead the AES or the IFE triggers a series of two LIDUs controlling and resuming the already existing opened logical channels for the IFE sms/mails and IFE BITE functions. These LIDUs include either the code 0x39FE or 0x39FF for the logical channels FE and FF respectively.

Table 3 presents the measurements of the above-described messages timings in order to determine the "standard values" during a normal flight, which will serve as a reference later in this study. The reported time durations are actually the time difference between the Log-on acknowledgment LIDU from the ground via the P10500 channel (cf. last row in Table 2) and the message in question indicated in the header of each column of Table 3. In a system point of view, these values indicate the reaction time to proceed with the normal establishment of the functionalities. The average values will provide the standard operational behaviour if the statistics are found adequate.

As the statistics are very good, one can use the averages as a first approximation of the standard behaviour of the systems. Thus, one can consider that MH371 service standard time intervals from the "Ground Log-on acknowledgment" message are:

- Link test (Q0x) = ~ 4s
- Media Advisory (SAx) = ~ 16s
- IFE sms/mail logon (0x01FF[4]) = ~ 65s
- IFE BITE logon (0x01FE) = ~ 71s
- FE Channel resuming ~ 2s
- FF Channel resuming ~ 7s

These values will serve as the reference in comparison with MH370 data in Section 4.1.2 below.

[4] Sometimes channels FF and FE are inverted

Table 2: Timing of MH371 ACARS, IFE and channel management signal units

Timing (seconds)						
	ACARS		IFE		Logical Channels resuming	
Log-on #	Q0x	SAx	SMS/mails	BITE	FE	FF
1-POR	4	14	64	70		
2-IOR	4	13	62	68		
3-POR	4	18	65	71		
4-IOR	5	18	67	73		
5-POR	4	14	63	69		
6-IOR	3	22	64	69		
7-POR	4	18	65	70		
8-IOR	4	14	65	70		
*12-POR	4	16	67	73		
13-IOR	4	17	67	72		
14-POR	4	15	67	76		
15-IOR	3	15	63	69		
16-POR	4	14	64	70		
17-IOR	4	14	64	80		
18-POR	4	13	62	69		
†19-IOR	12	21	64	70		
†20-POR	5	23	66	76		
21-IOR	4	13	65	67		
22-POR	4	15	64	70		
23-IOR	4	13	65	71		
24-POR	4	14	63	70		
25-IOR	4	16	64	72		
	Landing					
26-IOR	*Immediately followed by 27-IOR*					
27-IOR	4	19	-	-	2	7
28-IOR	4	16	68	73	2[a]	5[a]
29-IOR	4	15	-	-	2	4
30-IOR	4	18	-	-	2	10
Average	4	16	65	71	2	7
Max	12	23	68	80		10
Min	3	13	62	67		4
Std Dev.	1.6	2.8	1.7	3		2.3

** Log-on attempts 9 to 11 failed or completed but were directly followed by a new Log-on.*

† Log-on 19 and 20 intervened in the middle of ACARS data transmission messages.

[a] These flow control signal units were followed by a prior connection release of each channel.

4.3.2 MH370 service

Considering MH370 service, the situation is very different as only 6 Log-on requests were successfully submitted by the SDU. Prior to these, at 09:01:28 UTC, the AES did not respond to a Log-on interrogation (a ping) from the ground via IOR satellite. It is only at 12:50:19 UTC that the AES sent a type 1 Log-on request. This means that, at that time, no flight information had been received via the ARINC 429 bus. Then came three type 2 Log-on requests while the aircraft was still at the gate. They were followed by two Log-on requests in flight at 18h25:27 UTC and 00h19. Both were of type 1 meaning that no flight information was available.

4.3.2.1 Operational sequence of Events for MH370

Table 4: Operational sequence of MH370 events from pre-flight preparation till the end of flight summarises the key events in Inmarsat context and their timing including also the operational pre-flight preparations ahead of MH370 service. They have been interpreted based on experience and referring to the Standard Operating Procedures from experience or like the ones indicated in [7] for example. The third column makes the link between the system view and the operational actions from the cockpit when possible.

Table 3: Operational sequence of MH370 events from pre-flight preparation till the end of flight

Time UTC	***Event***	***Interpretation***
08:02:27	Last LIDU sent by the AES for MH371	• MH371 flight closure under way
09:01:28	No response to a Log-on interrogation	• Most likely aircraft left main AC bus was powered off between services (probably the full aircraft was power-off) • At home hub, this is a typical habit to have the aircraft "switched-off" between two services
12:50:19	Log-on request from the AES with header 0x1F via POR satellite Low gain antenna was used. Logon # 31 in the Signal Units Log report.	• 0x1F: no flight information (previous flight was closed erasing all flight data) • SDU got power back most likely because the aircraft power was switched back on (most likely via primary ground external power with bus ties or via secondary external power cf ACARS message below) • It is about 4hours before take-off. At this point in time and being at Malaysian hub, this "wake-up" was most probably due to the maintenance team verifying and fixing logs/ issues of the previous services reported by the crew in the Technical Log Book and from the EICAS reports. • The fact that the low gain antenna was used reveals that the ADIRU was not transmitting the aircraft position. Thus, this is an additional element to indicate that the aircraft was powered off prior to this log-on.
12:50:32	AES LIDU of type Q0x with correct aircraft tail number9M-MRO but dummy flight number MH0000 The message tag is Q00 i.e. type Q0 with sequence number 0. It comes after previous Q07 and SA8 messages without Q09 or SA9 in between. No message was lost as the subsequent ground responses properly followed their numbering sequence with no jump from "J" to "K" between SA8 and Q00. In addition, the ACARS counter was at S16A (after completing a S99A loop at 6:09:53) and thus was reset to S00A. Thus, the sequence had been reset.	• ACARS link test message including the aircraft dependent information but no flight information. At that point in time no reason for having the flight number already input as no crew is on board yet. This message is for the establishment of a connection • The two concurrent 0 values of the loop counters mean that the AES/ACARS system had reset the different on-board numbering sequences. • In addition, the R-Channel loop counter and T-Channel loop counter were reset. • These counters resets advocate for a power break before 9h01:49 UTC.

	Absence of Media Advisory message from ACARS normally generated when a link status changes and sent over any other media link that is available.	• ACARS service has started but is currently transferring messages via the VHF and the SATCOM had not been "selected/authorised" yet. • The missing messages numbered S02A, S03A and S05A were transmitted via VHF. The two bursts S04A and S06A signal a proper media transfer from VHF to SATCOM around 15h55:00.
12:53:02 13:38:49	Several IFE only signal units from the EAS showing probable successive reboots and connection sequences including the funny "Pet Shop Boys…"[5] phrase These connection requests always came in a pair: first a request for the sms/mail (usually on logical channel FF) via the R-Channel and for the IFE BITE on logical FE channel via the T-Channel.	• The chain of characters "Pet Shop Boys…" appears to be a kind of "no void" user data to verify that the Data-3 connection is properly running in the context of the BITE. • It appears that the IFE uses the following naming convention for the flight ID: "MASxxx". At 13:38:47 it sent the first user data packet including a dummy flight ID "MAS000" (and not MH0000 used by ACARS). • Operationally, it appears that tests or maintenance activities were on-going in the aircraft.
14:35:53 & 15:36:02	Positive responses from the AES to Log-On Interrogations from the GES	• The SDU was powered-on • No message was sent since no active application needed communication (inactivity) • Probably nobody in the aircraft anymore
15:42:47	AES sends the usual SNDPU signalling 4 octets "…10 FF 00 00…" commanding the connection release of the Data-3 FF logical Channel and later the AES commanded the connection release of the Data-3 FE Channel. Their R-Channel octal sequential numbers 0o017 and 0o011 (i.e. 0x0F and 0x09) were in sequence and logically followed the last one sent at 13:24:08 with sequential number 0o016 (0x0E). The value 0o011 is the next value of the octal periodic loop ranging from 0o011 to 0o017.	• This is one hour before take-off, the pilot or the co-pilot took his duty in the cockpit (most probably) • IFE Data-3 connection was released (the IFE had kept in its memory that logical channels FE/FF were still opened) and then visible communication traffic occurred. • Wake-up after 2h04 approx. of "inactivity" • Normal incremental increase of the loop counters
15:43:30	AES sends the usual SNDPU signalling 4 octets "…01 FF 00 00…" which is an IFE Data-3 Channel Connection request with logical channel FF. Its R-Channel sequential number was 0o012 and was properly in sequence.	• Connection of the Sms & email IFE application
15:43:51	The Sms-email IFE application sent a data user packet with incomplete flight information data.	• Only the AES ID is valid • Missing Flight ID and airports ICAO codes

[5] *«Pet Shop Boys» is the name of a British singing boys band formed in 1981 : a sense of humour of the test designer ?*

	Its T-Channel sequential number was 0x07 and was in sequence.	• Most probably, these info were not yet filled in via the communication manager application on the MFD (manually or automatically).
15:43:51	Automatic message from IFE Sms & email data user packet with incomplete flight information data	• Same interpretation as above, the flight info was not yet filled in.
15:44:38	AES sends the usual SNDPU signalling 4 octets "…01 FE 00 00…" which is an IFE Data-3 Channel Connection request with logical channel FE. Its T-Channel sequential number was 0x09 (which is equivalent to 0x01 modulo 8) was in sequence after the message at 15:43:51.	• Connection of the BITE IFE application with "Pet Shop Boys…".
15:54:55	AES ACARS LIDU of type SAx (with loop up-counter number SA1) with correct aircraft tail number 9M-MRO but with dummy flight number MH0000 The loop up-counter SA1 shows that no message was lost after the Q00 message at 12h50:32 which included the ACARS sequence number S00A. But the ACARS loop up-counter number had jumped to S04A showing that intermediate messages were exchanged via another media (VHF) which is confirmed by the subsequent ground response alphabetical up-counter naturally incremented from "K" to "L" indicating that the SATCOM link did not lose any message.	• ACARS Media Advisory LIDU establishing a link via the default media (SATCOM) .i.e. ACARS switched from VHF (current media available) to Satellite media. • Most likely, the crew was proceeding with the checklist and **had performed a DATA LINK RESET of the Flight Deck Communication Function (FDCF)** which causes the centre VHF radio to be selected as the default media in data mode. This would explain that the messages S02A, S03A sent via VHF are not visible in the SATCOM log. The crew had just selected "ACARS MODE SATCOM" on the ACARS manager Page 2/2. • The missing Flight ID indicates that the crew did not enter this information yet. This is coherent with the context of the on-going Data Link Reset which resets airline parameters and flight information to power up configuration. Thus, the flight ID should take place afterwards.
15:55:07	AES LIDU of type SAx with loop up-counter number SA2 encompassing a correct aircraft tail number 9M-MRO but a dummy flight number MH0000. Here again, the ACARS loop up-counter number S06A shows that message S05A was exchanged via another media (i.e. VHF) which is confirmed by the subsequent ground response alphabetical up-counter continuously incremented by one from "L" to "M".	• ACARS Media Advisory LIDU confirming the switch from VHF to SATCOM media ("S" is provided as the "current Media available") • No message was lost via the satellite media.
	No explicit Log-off.	*No change of satellite*
15:55:57	New Log-on request from the AES with headers 0x2F/0x3F via POR satellite (same satellite). This occurred basically 1 minute after the last crew action.	• 0x2F/0x3F sequence indicates that flight information was available to the SDU via the ARINC 429 bus. • The crew had entered the flight information. • No power shutdown when considering the time

	Low gain antenna in use. Logon # 32.	elapsed since the last ISU (30s). • The fact that the low gain antenna was used reveals that the ADIRU was most likely still not transmitting the aircraft position. (It was probably still in its alignment phase).
15:56:09	AES LIDU of type Q0x with correct aircraft tail number 9M-MRO and correct flight number MH0370. Its loop up-counter number was Q03 correctly incremented from the previous SA2. Its ACARS loop up-counter number S07A is also normally incremented by 1 as well as the subsequent ground response alphabetical up-counter naturally incremented by one from "M" to "N".	• ACARS routine Link Test of the current media SATCOM after a new Log-on. • First ACARS message including the correct Flight ID.
15:56:22	AES LIDU of type SAx with the correct aircraft tail number 9M-MRO and the correct flight number MH0370. Its loop up-counter number was SA4 normally incremented from the previous Q03. Its ACARS loop up-counter number S08A is also normally incremented by 1 as well as the subsequent ground response alphabetical up-counter naturally incremented by one from "N" to "O".	• ACARS Media Advisory LIDU: routine message because the link media changed to the SATCOM. • Flight ID included.
	No explicit Log-off.	*No change of satellite*
15:57:49	Log-on request from the AES with headers 0x2F/0x3F via POR satellite (same satellite). High gain antenna in use. Logon # 33.	• 0x2F/0x3F: flight information is still available to the SDU via the ARINC 429 bus. • The fact that the high gain antenna was used reveals that the ADIRU was transmitting the aircraft position. Thus, as from this moment, the beam steering could ensure a proper pointing triggering a new log-on request for higher link capacity. • The time laps since the last ISU (73s) may be explained by the time needed to steer the HG antenna.
15:57:59 to 15:58:16	Several attempts "…0x39 FF…" or "…0x39 FE…" to resume and control the flow on FE and FF channels. One attempt shows a one-byte loss. A pair of ACARS messages went through: Q05 and SA6 (resp S09A and S10A) with subsequent ground responses labelled "P" and "Q"	• The attempts to check the link quality are correlated by the low level of the received power by the ground. • the received power was below -60dBm on R & T Channels. • This low signal power was the most probable reason which triggered a proper satellite handover procedure as during MH371 service (including an explicit Log-off request by the user cf. next row).

15:59:45	Log-off request properly acknowledged by the ground	• *Handover from POR to IOR satellite*
15:59:55	Log-on request from the AES with headers 0x2F/0x3F via IOR satellite (different satellite). High gain antenna in use. Logon # 34 in the Signal Units Log report.	• 0x2F/0x3F: flight information is still available to the SDU via the ARINC 429 bus. • In average, the received power had improved by 3 to 4 dBm and was almost always above -58dBm. • This was the last Log-on before take-off.
16:00:17 to 17:07:48	A pair of ACARS messages went through: Q07 and SA8 (resp S11A and S12A) with subsequent ground responses labelled “R” and “S” IFE sms/mail and BITE connections with sequential numbers 0o01 and 0x01. Cockpit Printer messages concerning the load sheet were received and tagged from C1T to C1Z (at 16:07:08) and C1A (after having completed the alphabet loop) acknowledged by the cockpit via an airline defined message “81 7” (ACARS sequential number M00A with a subsequent ground response labelled “B” following the adequate sequence) An isolated ACARS Media Advisory message went through: SA8 (S21A) with a subsequent ground response labelled “C”). A series of 14 general ACARS messages of type “H1x” followed: position reports, Engines Health Monitoring etc.	• This sequence of messages is nominal and the different up-counters followed their normal respective incremental pace. • The ACARS sequence OOOI was normally followed from Out of the gate to Take-off.
17:07:48	Last message from the AES in this normal sequence. Acknowledgement of good reception of the ground message in response to previous AES message D03D.	• At that time, the different up-counters values were the following: ACARS counter = 3 Safety: AES T-Channel Q7/Ref counter = 0x73 AES R-Channel Q7/Ref counter = 0x72 IFE: AES T-Channel Q0/Ref counter = 0x03 AES R-Channel Q0/Ref counter = 0x01 AES Data counter (Ascii) = D03D Ground alphabetical counter = R Ground Q/Ref counter = 0x7A

		• From this moment no message was sent by the AES until 18:25:27
18:03:41 & 18:05:11	A series of two similar messages were sent to the cockpit printer from the ground tagged with an identical ACARS code C1S including the correct ground alphabetical counter = S	
18:06:08	Explicit Log-off because of "Unresponsive AES"	• The absence of response to the C1S messages led the network to log the AES off. This is recorded in the AES process log file. • This where, in the absence of request for Log-off or Log-on, it is concluded that the SDU had been without power at that time. • This is in coherence with the next Log-on request below.
18:25:27	Log-on request from the AES with header 0x1F via IOR satellite (same satellite). High gain antenna was used. Logon # 35.	• 0x1F header indicates that no flight information was available to the SDU via the ARINC429 bus. • The fact that the high gain antenna was used reveals that the ADIRU was transmitting the aircraft position. • The Log-on was nominally completed with the exact same sequence as at 12:50:19 except the AES class 3 instead of 1 because of the high gain antenna was currently in service. • Designated as Ping (Arc) 1 • SDU got power back most likely because IDG generators were switched back on
18:27:04	AES sent the SNDPU signalling 4 octets "…01 FF 00 00… " which is an IFE Data-3 Channel Connection request for logical channel FF. Its R-Channel sequential number was 0o011 resetting the octal counter loop.	• Connection of the Sms & email IFE application • Unusual behaviour because it lost memory that it had already opened the FF channel (it should have remembered that this channel was already opened and should have proceeded with a "resume" request) • Abnormal: The R-Channel incremental octal counter was reset
18:28:10	AES sent the usual SNDPU signalling 4 octets "…01 FE 00 00… " which is an IFE Data-3 Channel Connection request for logical channel FE. Its T-Channel sequential number was 0x09 (equivalent to 0x01 modulo 8) which is not in sequence, it reset the loop after the message numbered 0x03 at 16:42:03.	• Connection of the BITE IFE application "Pet Shop Boys…". • Unusual behaviour because it lost memory that it had already opened the FE channel (it should have remembered that this channel was already opened and should have proceeded with a "resume" request) • Abnormal: The T-Channel incremental counter was reset
18:28:15	Acknowledgement of user data by the AES	

18:39:52 to 18:40:56	Telephone call attempts from the ground	• C-Channel which provided BFO data only
19:41:01 to 22:41:22	Log-on interrogations from the ground with acknowledgement from the AES via the R-Channel	• Pings (Arcs) 2 to 5
23:14:01	Telephone call attempts from the ground	• C-Channel which provided BFO data only
00:10:58	Log-on interrogations from the ground with acknowledgement from the AES	• Ping (Arcs) 6
00:19:29	Log-on request from the AES with header 0x1F via IOR satellite (same satellite). High gain antenna was used. Logon # 36. No subsequent ACARS or IFE signal units.	• 0x1F header indicates that flight information was not received by the SDU over the ARINC 429 bus. • The fact that the high gain antenna was used reveals that the ADIRU was transmitting the aircraft position properly received via the ARINC429 bus. • The Log-on was properly completed with the exact same sequence as the one at 18:25:27. • This is designated as Ping (Arc) 7 • SDU got power back most likely because the APU generator was started.
00:19:37	Log-off request properly acknowledged by the AES (and later by the ground)	• Log-on sequence completed
	No explicit Log-off.	• No handover to POR satellite • The missing of subsequent ACARS and IFE signal units advocates for a power off of the SDU.

Contrary to MH371, very few data is available. In MH371 service and airborne, it is noticeable that Safety messages (precedence Q=7 ACARS) and non-safety messages with precedence level Q=0 IFE proceeded in a systematic way. This was not the case during MH370.

The presence and the absence of these messages provide valuable information as shown in the next paragraph.

4.3.2.2 Timing of the ACARS and IFE signal units

When a change of satellite occurs (handover) and after few seconds of the completed typical Log-on sequence as illustrated in Table 2, the normal process is that the aircraft ACARS systematically proceeds with the test of the link via an LIDU of the type “Link Test Q0x” (x being a continuous sequential loop counter). Few seconds later it sends another LIDU – an ACARS Media Advisory signal unit – generated when the status of the link changes and sent over any other media link that is available (here it is the satellite).

When the AES logs in succession to the same satellite again, the ACARS link test and media advisory signal units series is not transmitted. Instead, the AES or IFE triggers another series of two flow control LIDUs (0x39) resuming the existing channels reserved for the IFE sms/mails and IFE BITE functions. These LIDUs include either the code 0x39 FE or 0x39 FF for the already assigned logical channels FE and FF respectively.

For MH370, the relevant messages timing was also computed from the log file in a similar way as for MH371. They are presented in Table 5: Timing of MH370 ACARS, IFE and channel management signal units. Some values post very different characteristics compared to MH371 and some are even missing. They must be analysed in three time-segments i.e. before the data link reset performed by the crew, then between this reset and take-off time and then after take-off.

Table 4: Timing of MH370 ACARS, IFE and channel management signal units

Timing (seconds)						
	ACARS		IFE		Logical Channels resuming	
Log-on #	Q0x	SAx	SMS/mails	BITE	FE	FF
12:50:19 31-POR	5	n/a	155	222		
Data Link Reset						
15:55:57 32-POR	4	17			2	7
15:57:49 33-POR	3	15			2	6
15:59:55 34-IOR	4	14	63	71		
Take off						
18:25:27 35-IOR	n/a	n/a	88	105		
00:19:29 36-IOR	n/a	n/a	n/a	n/a	n/a	n/a
Average	4	15	109	146	2	7
Max	5	17	155	222		7
Min	3	14	63	71		6

4.3.2.1 Comparison of MH371 and MH370 Timings of the ACARS and IFE signal units

Comparing these data to those of the stable MH371 service, which will serve as the reference, one can see and infer the following:

a) MH370 Log-on sequences timing and behaviour mimic those of MH371 only within the time window starting after the Data Link Reset (at 15:42 UTC) and closing at take-off i.e. for Log-ons #32, #33 and #34. During this time, the ACARS, IFE and logical channels LIDUs timing is basically identical to the timing measured for MH371. One can conclude that the other Log-on sequences (i.e. #31, #35 and #36) are of a different nature due to different context and systems status.

b) MH370 cold first Log-on #31 posts very different timing figures compared to the MH371 reference values coming from a "warm" system in flight. For example, MH370 IFE messages took much longer i.e. between twice or three times the duration of MH371 and likewise compared to the stable MH370 data after the activity resumed at 15:42 UTC for the check list. At this stage one can read this difference as resulting from the aircraft being on the ground where start-up (booting) tests are more extensive and need more time than those performed in flight.

c) After Log-on #31 at 12:50 UTC, the first ACARS link test LIDU (Q0x) was present with a standard timing but the Media Advisory (SAx) signal unit was missing. This is because at start time nobody had changed the ACARS media from the default data VHF media to the satellite media. This advocates strongly for considering this time as an aircraft power-up for maintenance.

d) After Log-on #35 at 18:25 UTC, in flight, the IFE messages took between 30% and 50% more time than the duration of MH371. This indicates that IFE needed more time and performed additional tasks compared to MH371. The logical conclusion is that it needed time to complete its initial start-up tests after a power-up. The IFE is powered from both AC Buses (and by 28V for passenger address for emergency functions). Some of its elements are powered by the left AC bus only like the IFE Master Control located in P210 power panel for example and other by the right AC bus.

e) At 18h25 UTC, Log-on #35 was via the same satellite (IOR) as for Log-on #34. Thus, the system should have initiated a series of two flow control / resume LIDUs for the two logical channels FE and FF in the same manner as it did for Log-on #33 at 15:57 UTC and during MH371 service with no exception. But it did not remember that it did open these channels already. This shows that the IFE system directly requested the establishment of the FE/FF logical channels because its memory of the existence of previously established FE/FF channels via the same satellite IOR was erased. The logical conclusion is that it was coming from a power-off of the IFE communications function.

f) At Log-on #35, the absence of expected Q0x/SAx ACARS LIDUs leads to the most logical conclusion that the ACARS system either was in the mode "Auto Message Off" or was in error. Selecting "Auto Message Off" can be easily manually done on the Master Manager page be the PIC.

g) The last Log-on #36 sequence was completed by the normal log-on acknowledgement from the ground as described in Table 2. But no ACARS or IFE signal unit was transmitted afterwards which could mean four situations: they were without electrical power, there were powered but had no time to boot, they were in error or they were disabled.

4.3.3 What to conclude?

What to conclude from this comparison of timings and events? The presence, but more importantly the absence of data brings valuable information for interpreting the status of the systems.

1. The absence of SAx media advisory message at 12:50 UTC after the first Log-on #31 for MH370 service shows that ACARS was functioning but that the SATCOM was not the default media. ACARS tested the satellite link only to verify that the satellite media was available. This provides additional substance to the interpretation that this Log-on #31 is the result of a power-up of the SDU coming from an aircraft power-up. This is also very much in line with an ACARS system starting up and normally setting the default media to central VHF (data mode) without any extra manual intervention to select the SATCOM and thus without the need to proceed with the media advisory SAx message.

   Correlating this with the already identified elements from other published analyses like the use of low gain antenna for example increases the probability of a power-up of the SDU at that time.

2. At 12:50 UTC, the very long time taken by the IFE (~2min30) to transmit its requests for log-on compared to the warm IFE requests during MH371 service and the one a little bit later during the MH370 service shows that it performed other tasks during this time. Considering that the timing of the same requests from the IFE at 18:25 UTC in flight is 50% shorter, one could conclude that - as during MH371 where no test in flight took place - this behaviour is due to self-tests at start up time on the ground and in flight (as the proportion fir the latter is coherent to the usual reported timings by pilots).
   This brings additional coherence to consider that at 12h50 UTC and 18h25 UTC, the SDU was changing status from power-off to power-up.

3. At 18h25 UTC, the absence of "resume" request LIDUs but the direct presence of Log-on LIDUs from the IFE indicates that the system recognised ab initio that the logical channels FE & FF were known to be released which should not have been the case normally for a log-on via the same satellite without a prior log-off request. The IFE went on and forced its log-on request via the satellite anyway. A power-up of the AC sources of the IFE is the most logical interpretation of this behaviour.

4. At 18h25 UTC, Log-on #35 includes a type 1 single LIDU Log-on indicating that the SDU was <u>not</u> receiving the flight information data via the ARINC 429 bus. How could this happen? Considering the FCOM document, it is indicated erasing the flight ID is a

consequence of a Data Link Reset in flight which must have been performed in time before the Log-on. Doing so selects the default media to be the central VHF in data mode.

5. At 18h25 UTC, the absence of the ACARS messages series Q0x/SAx indicates that after its power-up the ACARS was disabled immediately and put on “Auto Message Off” blocking it from sending any message anymore.

6. At 18h25 UTC, the IFE behaviour reveals that it rebooted which shows that most likely both AC buses where off prior to the requests for connection. This is an additional element to believe that the aircraft was powered by the RAT only. This, in addition to the blocking electromagnetic emissions and communications in particular, is very well in the spirit of making the aircraft untraceable and in line with the modus operandi described in [1].

7. At 00h19 UTC, an end of flight scenario as described in [1] shows that - just after having been powered-up - the SDU has been powered-off again at the very moment of the end of the completion of its log-on. This could explain the abnormal BFO of the last AES R-Channel transmission at 00:19:37 UTC.

5 The previous Satellite ID

Like in [11], we confirm that the previous satellite code provides a convincing clue for recognising a power-on cycle of the SATCOM. In fact, a Log-on request coming from the AES including a binary code value equals to 0b111111 (63 in decimal) is systematically transmitted each time the SATCOM had explicitly logged off as visible in Table 2 of [11] and in Table 7 in Appendix 1 of this report.

The “previous satellite” code is written in bits n°8 to 3 in octet n°9. For Satellite IOR its value is 0b000011 (3 in decimal) and for Satellite POR its 0b000010 (2 in decimal). If a proper log-off occurred before, the 6 bits are set to “1” thus with a code equal to 0b111111 (63 in decimal). Thus, considering that bits 2 and 1 represent the Beam Id which is always equal to 0b00 meaning Global beam, Octet n°9 reads 0x0C for IOR as previous satellite, 0x08 for POR as previous satellite and 0xFC when a proper log-off took place just before.

In addition, the absence of response from the SATCOM to the Log-on interrogation around 09:01 UTC is very likely due to a power down status of the SATCOM. Thus, one can make the hypothesis that at 18:25:27 UTC and 00:19:29 UTC having Log-on requests from the AES including this code without any prior corresponding proper logoff request means that a power-off /power-on cycle took place before these Log-on requests.

This is also supported by the value of the I/R flag used by the EAS during each Log-on request. Normally, when the EAS logs-on to the same satellite consecutively the I/R bit is always set to 1 meaning “renewal”. At 18h25 UTC, during Log-on #35, this flag was set to 0 showing that the AES had no recollection that its last connection was to IOR and that it was connecting to the same satellite again and thus it raised the I/R bit to 1. This “lost information” is an additional element in favour of a power-up at that time.

Likewise, at 00h19 UTC on March 8, during Log-on #36 the I/R bit was set to 0 which is an additional element in favour of a power-up at that time also.

6 A simple realistic scenario

The overall conclusion is that during the leg starting after the U-turn (after IGARI) and finishing at the ping #1 (Arc-1), the scenario of a manual piloting with the RAT as the only electrical power source is compatible with the sequence of events analysed above.

Thus, the probable scenario from IGARI to Ping 1 (Arc 1) is:

a) Shortly after the U-Turn towards Malaysia, the main sources of electrical power were disabled (IDG, Backup generators and the APU)

b) During the interim, the main battery supplied the necessary power

c) The RAT deployed and then provided the necessary standby electrical power after the power break.

d) The aircraft was piloted manually possibly using intermediate VOR radials. This is recognised as a possible procedure by pilots.

e) Around 18h23 UTC the IDG were switched back on. This powered up the SDU, the ACARS and the non-critical functions of the IFE. The electrical power was re-established at about the same time of exiting the Western Hill radar coverage. This was not a coincidence. This is convincingly justified by the hijacking modus operandi as described in [1].

f) Then a Reset Data Link command was executed via the Master Manager page before the SDU could become operational. This switched the ACARS media to the default central VHF in data mode. In addition, this reset the company and flight information to default values and thus making the Flight ID not available anymore.

g) Quickly afterwards, the ACARS was switched to “Auto Message Off” to block any message transmission as the Reset Data Link above had put it on.

h) The SDU reconnected to the Inmarsat network recognised only by the AES ID transmitted in all messages with no exception. The Log-on request could not include the missing flight ID.

This kept the aircraft as most anonymous as possible… successfully …

7 References

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[14] Private direct exchanges of information with Inmarsat

8 Appendix 1

The table below underlines part of the content of the relevant Signal Units exchanged via the Inmarsat satellite network.

Table 5: Full set of Log-on LIDUs from 00h51:59UTC to 00h19:37 UTC

Routing Time UTC*	***Sat.***	***Hexadecimal content***	***Comment (according to [AMS])***	***Log-on seq. nb***
MH371				
00:51:09	POR	**2F** D0 **10** 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 00:51:10,759 and: High-gain, Class3* *The High gain antenna was used showing that the ADIRU was functional and that the SATCOM was receiving aircraft position data via the ARINC 429 bus.* *The fact that the previous satellite was not 0b111111 reveals that there was no explicit log-off request.* *Class 3* *I/R (Initial/Renewal) bit at Octet n° 8/bit n°2 = 0 -> Log-on Initial*	***Initial Log-on request*** **2F**: The sequence indicator (first 4 bits) indicates 2 which means that this Log-on request is performed with Flight ID available (Type 2) **D(0)**: Q number (transmission precedence of the message) is 13 which is the highest non distress level (max is 15). Here it is for AES/GES management SUs. **10** - Log-on Request LIDU. EAS Id = 75 00 8F = dec 35200217 GES ID : 85 Hawaii via POR **D**: Application Q number, Same as above **0**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=0 Initial Log-on **0C**: Previous satellite:0b000011 (3) and Beam ID:0 05: Beam ID:0=Global Beam and nb of C channels=5 82: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) 09 Bit rate capability: code 1 = P-Ch 1200bit/s 00: antenna gain code 0: High gain	1
00:51:10,729	POR	3F D0 **10** 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *No recorded System "Log-on request" time as it is part of the sequence.* Strange: Class 1 for T channel … so SMS service? I/R (Initial/Renewal) bit at Byte 8/bit No2 = 1 -> Log-on Renewal JLM to verify: always on the same channel	**3F**: The sequence indicator (first 4 bits) indicates 3 as subsequent to the previous 2F Log-on (Type 2). *The decoding below is tentative only:* D(0): Q number (transmission precedence of the message) is 13 which is the highest non distress level (max is 15). Here it is for AES/GES management SUs. **10** - Log-on Request LIDU. EAS Id = 75 00 8F = dec 35200217 GES ID : 85 9: Application Q number, in this case "non-safety" T (possibly C) channel request signalling A: NOT (number of transmitters) :1 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=1=Log On renewal 82: Previous satellite:0b100000 (32) and Beam ID:0x10 A6: Beam ID: Spot beam ID=0b1010 : and nb of C channels=6 66: Class of AES: code 1 = Class 1 (Low gain antenna only, packet-mode services only) and Voice Characteristics: 0b101010 =unassigned 6E: Bit rate capability: 0b01101110 =	1

			P/R/T channels high rates 62: antenna gain = spare for low gain here 40-41 : spare	
01:07:18	POR	1F D0 12 75 00 8F 85 D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***Log-off from Log-on 1 on POR***	
01:07:29	IOR	2F D0 10 75 00 8F **C5** D**0** **F**C 05 82 09 00 00 00 00 00 97 1F *Recorded System Log-on request time: 01:07:30,478 and: High-gain, Class3* *The handover takes 11 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	**2F**: ***Exact copy of Initial Log-on 1*** except for the GES : C5= Perth via IOR and FC: Previous satellite:0b111111 (63) and Beam ID:0 **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	2
01:07:30,000	IOR	3F D0 10 75 00 8F **C5** 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *(then Logoff explicit because Log-on superseded by next request)*	**3F**: ***Exact copy of Log-on 1 renewal*** except for the GES : C5= Perth via IOR	
01:16:47	POR	**2F** D0 **10** 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 01:07:48,797 and: High-gain, Class3*	***Exact copy of Initial Log-on 1 via POR***	3
01:16:48,750	POR	3F D0 **10** 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 1 renewal via POR***	
01:20:09	IOR	2F D0 10 75 00 8F C5 D**0** **08** 05 82 09 00 00 00 00 00 6B 0A *Recorded System Log-on request time: 01:20:10,456 and: High-gain, Class3*	***Exact copy of Initial Log-on 2*** via IOR except for **08**: Previous satellite:0b000010 (2)	4
01:20:10,428	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal*** via IOR	
01:23:24,000	POR	**2F** D0 **10** 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 01:23:24,777 and: High-gain, Class3*	***Exact copy of Initial Log-on 1 via POR***	5
01:23:25,000	POR	3F D0 **10** 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 1 renewal via POR***	
01:26:41,451	IOR	2F D0 10 75 00 8F C5 D**0** **08** 05 82 09 00 00 00 00 00 6B 0A *Recorded System Log-on request time: 01:26:42,476 and: High-gain, Class3*	***Exact copy of Initial Log-on 4 via IOR***	6
01:26:42,441	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 (and 4) renewal via IOR***	
01:29:57	POR	2F D0 10 75 00 8F 85 D**0** 0C 05 82 09 00	***Exact copy of Initial Log-on 1 via POR***	7

		00 00 00 00 8B F8 *Recorded System Log-on request time: 01:29:58,756 and: High-gain, Class3*		
01:29:58,730	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53	***Exact copy of Log-on 1 renewal via POR***	
01:34:16		***Take-Off User data Unit***	*Take off at 01:34:xx*	
01:36:48	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 7 on POR)***	
01:36:59	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *Recorded System Log-on request time: 01:37:00,518 and: High-gain, Class3* *The handover takes 11 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	8
01:37:00,462	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
01:39:17	POR	2F D0 10 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 01:39:18,788 and: High-gain, Class3* *(Recorded as failed)*	***Exact copy of Initial Log-on 1 via POR***	
01:39:18,733	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 ***Failed:*** *Only channel control LIDUs (P/R and T channel control LIDUs) but no 0x15 ACK LIDU so unfinished log-on thus retry via IOR cf below Log-on 10* *(then Logoff implicit at 01:40:35 because Log-on failure)*	***Exact copy of Log-on 1 renewal via POR***	9
01:40:49	IOR	2F D0 10 75 00 8F C5 D**0** **0**C 05 82 09 00 00 00 00 00 8E 35 *Recorded System Log-on request time: 01:40:50,442 and: High-gain, Class3* *(Recorded as logged-on for 24s,)*	***Exact copy of Initial Log-on 2 via IOR*** except for **0**C: Previous satellite:0b000011 (3) *(IOR is still the last logged-on sat)*	
01:40:50,428	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E ***Incomplete sequence:*** *Only channel control LIDUs (P/R and T channel control LIDUs) but no 0x15 ACK LIDU so unfinished log-on thus retry via IOR cf below Log-on 11* *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	10
01:41:13	POR	2F D0 10 75 00 8F 85 D0 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time:*	***Exact copy of Initial Log-on 1 via POR*** with **0**C: Previous satellite:0b000011 (3) *(IOR is still the last logged-on sat)*	11

		01:41:14,756 *and: High-gain, Class3 (recorded as Failure)* ***Failed:*** *Only channel control LIDUs (P/R and T channel control LIDUs) but no 0x15 ACK LIDU so unfinished log-on thus retry via IOR cf below Log-on 12*		
01:41:14,769	POR	3F D0 10 75 00 8F 85 9A 82 A6 66 6E 62 40 41 00 00 1E 53 *(then Logoff implicit at 01:42:31 because Log-on failure)*	***Exact copy of Log-on 1 renewal via POR***	
01:42:57	POR	2F D0 10 75 00 8F 85 D0 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 01:42:58,776 and: High-gain, Class3* *Successful (4th attempt): Log-on on same POR satellite (back to square one).*	***Exact copy of Initial Log-on 1 via POR***	12
01:42:58,729	POR	3F D0 10 75 00 8F 85 9A 82 A6 66 6E 62 40 41 00 00 1E 53 *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 1 renewal via POR***	
01:55:23	IOR	2F D0 10 75 00 8F C5 D0 **08** 05 82 09 00 00 00 00 00 6B 0A *Recorded System Log-on request time: 01:55:24,483 and: High-gain, Class3*	***Exact copy of Initial Log-on 4 via IOR*** **08**: Previous satellite:0b000010 (2)	13
01:55:24,457	IOR	3F D0 10 75 00 8F C5 9A 82 A6 66 6E 62 40 41 00 00 1B 9E *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 (and 4) renewal via IOR***	
01:58:35	POR	2F D0 10 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8 *Recorded System Log-on request time: 01:58:36,757 and: High-gain, Class3*	***Exact copy of Initial Log-on 1 via POR***	14
01:58:36,730	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53	***Exact copy of Log-on 1 renewal via POR***	
03:19:58	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 14 on POR)***	
03:20:09,424	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *Recorded System Log-on request time: 03:10:20,420 and: High-gain, Class3* *The handover takes 11 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	15
03:20:10,424	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E	***Exact copy of Log-on 2 renewal via IOR***	
03:31:05	IOR	1F D0 12 75 00 8F **C5** D0 00 00 00 00 00 00 00 00 00 62 FF *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 15 on IOR)***	
03:31:15	POR	2F D0 10 75 00 8F 85 D**0** FC 05 82 09 00 00 00 00 00 92 D2 *Recorded System Log-on request time:*	***Exact copy of Initial Log-on 1 via POR*** with FC: Previous satellite:0b111111 (63)	16

		03:31:16,740 and: High-gain, Class3 *The handover takes 10 sec to log-on via POR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	**82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	
03:31:16	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53	***Exact copy of Log-on 1 renewal via POR***	
03:35:28	POR	1F D0 12 75 00 8F 85 D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 16 on POR)***	
03:35:53,439	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 25 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	17
03:35:54,437	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time: 03:35:54,437 and: High-gain, Class3*	***Exact copy of Log-on 2 renewal via IOR***	
04:00:47	IOR	1F D0 12 75 00 8F **C5** D0 00 00 00 00 00 00 00 00 00 62 FF *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 17 on IOR)***	
04:00:59,729	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 ***Ignored:*** *This LIDU seems to be an orphan and the unique signal unit on POR-R600-0-36D6 channel which obviously had trouble since the 2F LIDU did not come through (the best explanation being a possible packets collision on the channel).* *Antenna alignment not completed does not seem to be the issue as the Rx power and Noise ratio are in comparable ranges with previous and following Log-on's.*	***Exact copy of Log-on 1 renewal via POR***	
04:01:10,739	POR	2F D0 10 75 00 8F 85 D**0** FC 05 82 09 00 00 00 00 00 92 D2 *The handover takes 10 sec to log-on via POR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 1 via POR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	18
04:01:11,727	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *Recorded System Log-on request time: 04:01:11,727 and: High-gain, Class3*	***Exact copy of Log-on 1 renewal via POR***	
04:03:25	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 18 on POR)***	
04:03:35,421	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 10 sec to log-on via IOR: time to align the High Gain antenna*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC)	19

		with the new satellite This initial Log-on is via the High Gain antenna.	**09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	
04:03:36,421	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time: 04:03:36,431 and: High-gain, Class3*	***Exact copy of Log-on 2 renewal via IOR***	
04:55:47	IOR	1F D0 12 75 00 8F **C5** D0 00 00 00 00 00 00 00 00 00 62 FF *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 19 on IOR)***	
04:55:57,726	POR	2F D0 10 75 00 8F 85 D**0** FC 05 82 09 00 00 00 00 00 92 D2 *The handover takes 10 sec to log-on via POR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 1 via POR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	20
04:55:58,727	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *Recorded System Log-on request time: 04:55:58,728 and: High-gain, Class3*	***Exact copy of Log-on 1 renewal via POR***	
05:09:48	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 20 on POR)***	
05:10:15,421	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 27 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	21
05:10:16,423	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time: 05:10:16,424 and: High-gain, Class3* *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
05:37:35,740	POR	2F D0 10 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8	***Exact copy of Initial Log-on 1 via POR***	
05:37:36,742	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *Recorded System Log-on request time: 05:37:36,792 and: High-gain, Class3*	***Exact copy of Log-on 1 renewal via POR***	22
06:09:25	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 22 on POR)***	
06:09:33,454	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 7 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	23
06:09:34,416	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E	***Exact copy of Log-on 2 renewal via IOR***	

		Recorded System Log-on request time: 06:09:34,415 and: High-gain, Class3 *(then Logoff explicit because Log-on superseded by next request)*		
06:16:21,731	POR	2F D0 10 75 00 8F 85 D**0** 0C 05 82 09 00 00 00 00 00 8B F8	***Exact copy of Initial Log-on 1 via POR***	24
06:16:22,731	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 62 40 41 00 00 1E 53 *Recorded System Log-on request time: 06:16:22,759 and: High-gain, Class3*	***Exact copy of Log-on 1 renewal via POR***	
06:48:08	POR	1F D0 12 75 00 8F **85** D0 00 00 00 00 00 00 00 00 00 67 32 *(Mobile Initiated Logoff)*	***1F: Log control (R channel)-log-off request (from Log-on 24 on POR)***	
06:48:19,429	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 7 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna.*	***Exact copy of Initial Log-on 2 via IOR*** with FC: Previous satellite:0b111111 (63) **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09**: Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	25
06:48:20,414	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time: 06:48:20,415 and: High-gain , Class3* *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
07:28:28		***Touch Down at Beijing Data Unit***		
07:29:21,415	IOR	2F D0 10 75 00 8F C5 D**2** 0C 05 **0**2 0**1** 00 00 00 00 00 85 CA *Appears as a technical adjustment of the class of AES from Class 3 downgraded to Class1. Because connection made via Low-Gain antenna.*	***Log-on renewal via IOR*** **…** **D2**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=**1** Renewal Log-on **…** **0**2: Class of AES: code 0 = Class 1 and Voice Characteristics: 2 (2x9 600 LPC) 0**1**: Bit rate capability: code 1 = P-Ch 1200bit/s *(in fact no change compared to 09 as Bit 8 is unassigned)* …	26
07:29:22,411	IOR	3F D0 10 75 00 8F C5 9A 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time as **RENEWAL**: 07:29:22,415 and: Low-gain , Class1* *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
07:29:35,414	IOR	2F D0 10 75 00 8F C5 D**2** 0C 05 **8**2 0**9** 00 00 00 00 00 C0 6D *Appears as a technical adjustment of the class of AES from Class 1 upgraded to Class 3 because new connexion via High Gain antenna.*	***Log-on renewal via IOR*** **…** **D2**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=**1** Renewal Log-on **…** **8**2: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) 0**9** Bit rate capability: code 1 = P-Ch 1200bit/s	27

07:29:36,411	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time as* ***RENEWAL****: 07:29:36,439* *and: High-gain , Class3* *(then Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
07:36:37,412	IOR	2F D0 10 75 00 8F C5 **D2** 0C 05 **0**2 0**1** 00 00 00 00 00 85 CA *Appears as a technical adjustment of the class of AES from Class 3 downgraded to Class1. Temporary technical issue or a temporary error? or just because taxiing and having reflection/interferences or ghosts ? Because connection made via Low-Gain antenna.*	***Log-on renewal* same as Log-on 26 *via IOR*** **…** **D2**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=**1** Renewal Log-on **…** **0**2: Class of AES: code 0 = Class 1 and Voice Characteristics: 2 (2x9 600 LPC) 0**1**: Bit rate capability: code 1 = P-Ch 1200bit/s *(same as 07:29:35)* 00: antenna gain code 0: still on High gain	28
07:36:38,411	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time as* ***RENEWAL****: 07:36:38,436* *and: Low-gain , Class1* *(Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	
07:37:32		***Aircraft at the Gate in Kuala Lumpur***		
07:58:13,411	IOR	2F D0 10 75 00 8F C5 D**2** 0C 05 **8**2 0**9** 00 00 00 00 00 C0 6D *Adjustment of the class of AES from Class 1 upgraded to Class 3. Because connection made via High-Gain antenna.*	***Log-on renewal same as Log-on 27 via IOR***	
07:58:14,443	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time as* ***RENEWAL****:* *07:58:14,447 (Log-on superseded)* *and: High-gain , Class3* *(Logoff explicit because Log-on superseded by next request)*	***Exact copy of Log-on 2 renewal via IOR***	29
08:01:53,411	IOR	2F D0 10 75 00 8F C5 D**2** 0C 05 **0**2 0**1** 00 00 00 00 00 85 CA *Adjustment of the class of AES from Class 3 downgraded to Class1. Because connection made via Low-Gain antenna.*	***"Bis repetiti placent" Log-on renewal* same as Log-on 26 and 28 *via IOR***	
08:01:54,411	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 62 40 41 00 00 1B 9E *Recorded System Log-on request time as* ***RENEWAL****: 08:01:54,437* *and: Low-gain , Class1*	***Exact copy of Log-on 2 renewal via IOR***	30
09:01:28	***IOR***	***Log Control – Log-on Interrogation***	*Handshake to check if AES is up,* ***no answer from AES*** *thus implicit Log-off by Inmarsat because of* ***Log-on Verification Failure***	
After 09:01:28	***IOR***	*The aircraft was most probably in an Electrical Power Off status between the completed MH371 service and the future MH370 service.*	*Aircraft resting at C1 gate probably.*	
MH370				

12:50:19,735	POR	**1F** D0 10 75 00 8F 85 D**0** FC 05 **0**2 01 00 00 00 00 00 F4 6C *__1F__: The sequence indicator (first 4 bits) indicates __1__ meaning that this Log-on request is a genuine initial Log-on LIDU and is the first one after a most probable power off/power on sequence.* *Recorded System Log-on request time as __INITIAL__:* *12:50:19,736 (Log-on superseded)* *and: Low-gain antenna, Class1*	***1st Initial Log-on for MH370 (type 1)*** **1F**: The sequence indicator (first 4 bits) indicates **1** meaning that this Log-on request is a genuine *initial Log-on* LIDU. **D(0)**: Q number (transmission precedence of the message) is 13 (Link Layer protocol) which is the highest non distress level (max is 15). Here it is for AES/GES management SUs. **10** - Log-on Request LIDU. EAS Id = 75 00 8F = 0o35200217 GES ID: 85 Hawaii via POR **D**: Application Q number, Same as above **0**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=0 Initial Log-on **FC**: Previous satellite: 0b111111 (63) and Beam ID:0 05: Beam ID:0=Global Beam and nb of C channels=5 **0**2: Class of AES: code 0 = Class 1 and Voice Characteristics: 2 (2x9 600 LPC) 0**1**: Bit rate capability: code 1 = P-Ch 1200bit/s 00: antenna gain code 0: But Class1 : spare	31
14:35:51	***POR***	***0x14 - Log-on Interrogation by the GES***	*Handshake to check if AES is up*	
14:35:53	***POR***	1F D0 15 75 00 8F 85 D0 10 14 00 00 00 00 00 00 00 92 70	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
15:36:00	***POR***	***0x14 - Log-on Interrogation by the GES***	*Handshake to check if AES is up*	
15:36:02	***POR***	1F D0 15 75 00 8F 85 D0 10 14 00 00 00 00 00 00 00 92 70 *(Logoff explicit because Log-on superseded by next request)*	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
15:55:57,734	POR	2F D0 10 75 00 8F 85 D**2** **08** 05 02 01 00 00 00 00 00 65 38 (0**2**: Class 1 so de facto low gain Antenna)	***Renewal Log-on for MH370 (type 2)*** similar to Log-on 31 except (D)**2**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=**1** Renewal Log-on **08**: Previous satellite:0b000010 (2)	32
15:55:58,735	POR	3F D0 **10** 75 00 8F 85 9**A** 82 A6 66 6E 60 40 41 00 00 96 45 *Recorded System Log-on request time as renewal and: Low-gain antenna, Class1* *(Logoff explicit because Log-on superseded by next request)*	***Renewal Log-on*** similar to Log-on Renewal 31 except **3F**: The sequence indicator (first 4 bits) indicates 3 as subsequent to the previous 2F Log-on LIDU D(0): Q number (transmission precedence of the message) is 13 which is the highest non distress level (max is 15). Here it is for AES/GES management Sus. **10** - Log-on Request LIDU. EAS Id = 75 00 8F = dec 35200217 GES ID : 85 via POR **9**: Application Q number, in this case "non-safety" T (possibly C) channel request signalling **A**: NOT (number of transmitters) :1 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=1=Log On renewal **82**: Previous satellite:0b100000 (32) and Beam ID:0x10 **A6**: Beam ID: Spot beam ID=0b1010 : and nb of C channels=6	

			66: Class of AES: code 1 = Class 1 (Low gain antenna only, packet-mode services only) and Voice Characteristics: 0b101010 =unassigned **6E**: Bit rate capability: 0b01101110 = P/R/T channels high rates **60**: antenna gain = spare for low gain here 40-41 : spare ???	
15:57:49,735	POR	2F D0 10 75 00 8F 85 D**2** 08 05 **82 09 00** 00 00 00 00 20 9F *It appears that the High Gain Antenna got aligned and in function: so new logon with better capabilities… 2F : this means that the correct aircraft position was provided to the SDU (ADIRU aligned ?)*	***Renewal Log-on for MH370*** similar to Log-on 32 with (D)**2**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=**1** Renewal Log-on except: **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09** Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	33
15:57:50,735	POR	3F D0 10 75 00 8F 85 9**A** 82 A6 66 6E 60 40 41 00 00 96 45 *Recorded System Log-on request time as* ***RENEWAL****: 15:57:50,761* *and: High-gain , Class3*	***Renewal Log-on*** similar to Log-on renewal 32	
15:59:45,229	POR	1F D0 12 75 00 8F 85 D0 00 00 00 00 00 00 00 00 00 67 32 *(**Mobile Initiated** Logoff effective 15:59:45,743)*	***1F: Log control (R channel)-log-off request (from Log-on 33 on POR)***	
15:59:55,413	IOR	2F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 97 1F *The handover takes 10 sec to log-on via IOR: time to align the High Gain antenna with the new satellite This initial Log-on is via the High Gain antenna. 2F: the correct aircraft position was provided to the SDU.* *Previous satellite = b x111111 because prior proper log-off.*	***2nd Initial Log-on request but via IOR (type 2)*** **(D)0**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=0 Initial Log-on FC: Previous satellite:0b111111 (63) and Beam ID:0 **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09** Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	34
15:59:56,413	IOR	3F D0 10 75 00 8F C5 9**A** 82 A6 66 6E 60 40 41 00 00 93 88 *Recorded System Log-on request time as* ***INITIAL****: 15:59:56,414* *and: High-gain, Class3*	***Renewal Log-on*** similar to Log-on renewal 32 but via IOR	
16:41:58		***Take-Off User data Unit***	*Take off at 16:41:xx*	
		SATCOM not transmitting since 17:37:48	***EHMS ½ hourly report missing***	
18:06:08,351	IOR	Logoff Explicit: Unresponsive AES	*The reason comes from the absence of response to the phone call.*	
18:25:27,421	IOR	1F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 B4 06 *Recorded System Log-on request time as* ***INITIAL****: 18:25:27,421* *and: High-gain , Class3* *1F numbering of this LIDU is similar to the genuine 1st initial Log-on request LIDU at 12:50:19 for the MH370. It is thus a genuine Log-on request* *This supports the hypothesis that the*	***3rd Initial Log-on request but via IOR (type 1)*** **(D)0**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=0 Initial Log-on FC: Previous satellite:0b111111 (63) and Beam ID:0 **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09** Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	35

		SATCOM had rebooted after a power-off since it did not transmit at 17:37 and did not reply at 18:03 and 18:05. *This LIDU was transmitted via the High Gain antenna. This indicates that the ADIRU position data were transmitted properly to the SATCOM over the ARINC data bus.*		
19:41:01	***IOR***	***0x14 - Log-on Interrogation by the GES***	*Handshake 2 to check if AES is up*	
19:41:03	***IOR***	1F D0 15 75 00 8F C5 D0 10 14 00 00 00 00 00 00 00 97 BD	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
20:41:03	***IOR***	***0x14 - Log-on Interrogation by the GES***	*Handshake 3 to check if AES is up*	
20:41:05	***IOR***	1F D0 15 75 00 8F C5 D0 10 14 00 00 00 00 00 00 00 97 BD	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
21:41:25	***IOR***	***0x14 - Log-on Interrogation by the GES***	*Handshake 4 to check if AES is up*	
21:41:27	***IOR***	1F D0 15 75 00 8F C5 D0 10 14 00 00 00 00 00 00 00 97 BD	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
22:41:20	***IOR***	***0x14 - Log-on Interrogation by the GES***	*Handshake 5 to check if AES is up*	
22:41:21	***IOR***	1F D0 15 75 00 8F C5 D0 10 14 00 00 00 00 00 00 00 97 BD	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
00:10:58	***IOR***	***0x14 - Log-on Interrogation by the GES***	*Handshake 6 to check if AES is up*	
00:11:00	***IOR***	1F D0 15 75 00 8F C5 D0 10 14 00 00 00 00 00 00 00 97 BD	***0x15 - Log-on Acknowledge by EAS*** *Response from AES : Log-on maintained* *Message content is "D0 10 14"*	
00:19:29	***IOR***	1F D0 10 75 00 8F C5 D**0** FC 05 82 09 00 00 00 00 00 B4 06 *This supports the hypothesis that the SATCOM had rebooted after a power-off similarly to previous situations.* *This LIDU was transmitted via the High Gain antenna. This indicates that the ADIRU position data were transmitted properly to the SATCOM over the ARINC data bus.*	***3rd Initial Log-on request but via IOR (type 1)*** **(D)0**: NOT (number of transmitters) :0 and LOV: 0 (Ok to respond to log-on interrogation) and I/R=0 Initial Log-on FC: Previous satellite:0b111111 (63) and Beam ID:0 **82**: Class of AES: code 2 = Class 3 and Voice Characteristics: 2 (2x9 600 LPC) **09** Bit rate capability: code 1 = P-Ch 1200bit/s **00**: antenna gain code 0: High gain	36