Briefing note on the Inmarsat publication of 23–24 May 2014 pursuant to the occurrence of 9M–MRO on 7–8 March 2014

Paul Sladen, Nineteen Inch Networks, Nottingham GBR

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This briefing note offers a non-technical overview of Inmarsat logs published on 23/24 May 2014 and how these relate to a later redacted publication by the Malaysian DCA[1] on 27 May 2014.

1 Introduction

On 20/23 May 2014 CNN recorded television footage at Inmarsat HQ in London. This was broadcast on 24 May 2014 and subsequently screened as three cuts of varying length.[2] The bulk of material came from a one-to-one interview between CNN reporter Richard Quest and Inmarsat Director of Satellite Operations Mark Dickinson during the morning of 23 May 2014.

During this interview Dickinson openly displayed several pages of printed log files. These sections form the unredacted records of communication between Inmarsat's ground infrastructure and the Malaysian Boeing 777-2H6/ER aircraft cn. 28420 (9M–MRO) for 7 March 2014.

Figure 1: Reviewing a page of the unredacted signalling unit log files in London at Inmarsat HQ on 23 May 2014. LEFT: Mark Dickinson, Inmarsat. RIGHT: Richard Quest, CNN (CNN)

[1] Malaysian Department of Civil Aviation. www.dca.gov.my/mainpage/MH370 Data Communication Logs.pdf
[2] CNN broadcast lengths (and 1280×720 archive filesizes): 3m 34s (74 MB), 4m 54s (101 MB), 9m 46s (201 MB)

1.1 Radio frequencies

Boeing 777 aircraft are equipped with several radio-frequency communication systems. Amongst these are Airband VHF radio, long-distance HF radio and L-Band satellite. VHF Airband works immediately above the frequencies used for FM broadcasting and is at 108–137 MHz. HF (high-frequency) can travel longer distances because it uses much lower frequencies than VHF communication. Conversely, satellite Aero L-Band uses higher frequencies than VHF, receiving at 1545–1555 MHz and transmitting at 1646.5–1656.5 MHz. All three sets of frequencies can transport voice and simple Telex messaging/data support, at a level comparable to 1990s-era GSM mobile telephones.

The L-Band frequencies are close to those used by GPS, and so only work outdoors where there is direct line-of-sight to a satellite. Some other automatically-activated radios use the frequencies in-between: secondary RADAR responders at 1030 MHz/1090 MHz, and Emergency Locator Beacons (ELTs) at 406 MHz. We will only cover the Aero satellite radio communications.

1.2 ACARS and SATCOM

The Aircraft Communications Addressing and Reporting System (ACARS) performs transhipment of short messages and data fragments over the VHF, HF or Satcom links. At the other end of the links the ACARS network providers (a bit like an ISP) ensure the messages are transported onwards and delivered to each airline's operations centre. The dominant ACARS providers are SITA in Asia, and ARNIC in the Americas.

On the aircraft side, interaction with the ACARS applications, and configuration of Satcom takes place via two tablet-sized MCDUs in the centre pedestal of the cockpit. (Figure 2)

Figure 2: 9M-MRO cockpit. BOTTOM: Satcom Main Menu displayed on right-hand Multifunction Control Display Unit. MIDDLE: SELCALL/Registration reminder stickers. (Chris Finney GFDL 1.2)

The Multifunction Control Display Unit acts in a similar manner to a mobile phone. Several applications (eg. Weather, Diagnostics, Flight Management) can all be used from the same screen and keyboard. Some applications will only activate when the user chooses them, while others (eg. Position reporting, Out Off On In (OOOI), Engine Health) will normally run autonomously in the background. In Figure 2 the *left-hand* Multifunction Control Display Unit (MCDU) is shown displaying the choices Flight Management Computer (FMC) and Satellite (SAT).

2 ACARS Messages

Communications between aircraft and the ground are simple and text-based. Like with emails and HTML webpages, the underlying textual nature can be followed by humans. The grammar is terse, much akin to old telegraph and Telex messages, and without the excesses of word spacing and full-stops.

We will trace a single human-readable textual message, right through the stages of its preparation for transmission within the ACARS system in the aircraft, out via SATCOM, and until it reaches the Ground Earth Station (GES). We will then compare this with the published log files that are the subject of this briefing note.

2.1 ACARS Out Off On In

Just after 16:41:39 on 7 March 2014 the event reporter on-board the aircraft requested to transmit a message showing that the aircraft had taken off from a runway. This "sentence" was:

```
OFF01MAS370    /--071641WMKKZBAA
1641 492
```

The first line shows take-off time, plus departure and destination aerodrome; while the second line covers fuel availability. The individual "words" in the message are:

OFF01	event	taking *off* (first message)
MAS370	callsign	ICAO code *MAS+370* flight number
071641	timestamp	*07* March 2014 *16:41* UTC
WMKK	from	*Kuala Lumpur*
ZBAA	to	*Beijing Capital*
1641	time	*16:41* UTC
492	fuel	calculated *49,200 kg* fuel on-board (FOB)

2.2 ACARS Application

The OOOI event reporter is one of several applications that can run over the infrastructure provided by ACARS. These applications are like the many "apps" that can be found on a smartphone, each has a different use but all of then use the same display, keyboard, and network connection. To ensure that any reply can be routed back to the correct application on-board the aircraft some additional contextual information needs to be added at the start:

```
M02AMH0370OFF01MAS370    /--071641WMKKZBAA
1641 492
```

These are a message ID to allow for tracking, and the flight ID so that it is clear which flight segment this relates to:

M02A	message ID	*Message 02-A* (it can be anything unique)
MH0370	flight ID	IATA code *MH+0370* flight number
...	message	[see above]

2.3 ACARS Datalink Header

Each stage in preparing for transmission wraps the message with some extra information:

```
2.9M-MRO<NAK>122<STX>M02AMH0370OFF01MAS370    /--071641WMKKZBAA\r\n
1641 492<ETX>
```

With the extra header and footer parts, the main message it is still readable. New parts are:

2	mode	always *2*
9M-MRO	registration	aircraft registration, *9M-* is Malaysian
<NAK>	acknowledge	*Negative Acknowledgement*
12	label	a type *12* message
2	DBI	always *2*
<STX>	text	*Start of Text* part
...	message	[see above]
<ETX>	text	*End of Text* part

Hexadecimal view

At this point we will introduce a second representation of the same message, but using the values of the characters as the computer sees them. These values are shown as pairs of hexadecimal digits (0–F). We can follow the hex string and pick out the decimal numbers in the flight ID, the date/time, the fuel load, and the repeated characters in the registration '9M-MRO', the word 'OFF', the two hyphens '--', and the two airport codes 'WMKK' and 'ZBAA':

```
          32 2E 39 4D 2D 4D 52 4F 15 31 32 32 02 4D 30 32 41 4D 48 30 33
37 30 4F 46 46 30 31 4D 41 53 33 37 30 20 20 20 20 2F 2D 2D 30 37 31 36
34 31 57 4D 4B 4B 5A 42 41 41 0D 0A 31 36 34 31 20 34 39 32 03
```

2.4 ACARS Datalink parity

Humans work best with letters and words, but the computer is working with numbers. So far these values for the characters have all been limited to the 128 values between 0–127 (00–7F). Adding a parity bit means there are now 256 possible values between 0–255 (00–FF) and these are called **octets** because they consist of 8-bits. These extra values can be used for detecting errors because, although all of the values *are possible*, not all of the combinations *are allowed:*

```
          32 AE B9 CD AD CD 52 4F 15 31 32 32 02 CD B0 32 C1 CD C8 B0 B3
37 B0 4F 46 46 B0 31 CD C1 D3 B3 37 B0 20 20 20 20 2F AD AD B0 37 31 B6
34 31 57 CD CB CB DA C2 C1 C1 0D 8A 31 B6 34 31 20 34 B9 32 83
```

Half of the values have remained the same, and half have been altered in a predictable way:

number	encoding	with parity		number	encoding	with parity	
'0'	30	B0	←	'5'	35	B5	←
'1'	31	31		'6'	36	B6	←
'2'	32	32		'7'	37	37	
'3'	33	B3	←	'8'	38	38	
'4'	34	34		'9'	39	B9	←

2.5 ACARS Datalink checksum

The next stage is a checksum, which enables the integrity of the full message to be validated. A common everyday example of a checksum is the last digit on a credit card—which is not part of the number itself but is an artifact calculated by adding up the previous fifteen digits. Including the checksum digit makes it possible to quickly catch a number which has been read, or transcribed incorrectly.

For the ACARS checksum, a 16-bit Cyclic Redundancy Check (CRC16) is used for producing the summary. The particular CRC16 variant used is called “Kermit” (named after the frog), and starts with the value zero (`00 00`), before adding and multiplying the message values together.

```
<SOH>2.9M-MRO<NAK>122<STX>M02AMH0370OFF01MAS370␣␣␣␣/--071641WMKKZBAA\r\n
1641 492<ETX>8.<DEL>
```

```
␣␣␣␣␣␣01 32 AE B9 CD AD CD 52 4F 15 31 32 32 02 CD B0 32 C1 CD C8 B0 B3
37 B0 4F 46 46 B0 31 CD C1 D3 B3 37 B0 20 20 20 20 2F AD AD B0 37 31 B6
34 31 57 CD CB CB DA C2 C1 C1 0D 8A 31 B6 34 31 20 34 B9 32 83 B8 7E 7F
```

<SOH>	header	*Start Of Header*
...	message	[see above]
B8 7E	checksum	calculated total of previous octets
<DEL>	footer	*Delete*, end, stop processing

...

At this point the message is ready and is identical whether sent via VHF Com, via HF Com or via Satcom. The choice for how to send the message is one of availability verses cost. VHF is cheap, but only works near land. Inmarsat’s *Classic Aero* AMS(R)S service is expensive, but works across the whole globe with the only exceptions being close to the North and South poles.

The next step is to hand the complete encapsulated ACARS Datalink message to the aircraft’s Satellite Data Unit (SDU).

3 Satcom Data-2

ACARS messages can be transmitted over the Aeronautical Mobile Satellite (on-Route) Service (AMS(R)S), more commonly shortened to “Satcom”. When sending an ACARS messages via Satcom it is first “enveloped” but without any address. This leaves all of the decisions and complexity about where to forward the received ACARS message to the GES . All the Satellite Data Unit does is to add a two-octet header on the front consisting of `FF FF`.

```
..<SOH>2.9M-MRO<NAK>122<STX>M02AMH0370OFF01MAS370␣␣␣␣/--071641WMKKZBAA\r\n
1641 492<ETX>8.<DEL>
```

```
FF FF 01 32 AE B9 CD AD CD 52 4F 15 31 32 32 02 CD B0 32 C1 CD C8 B0 B3
37 B0 4F 46 46 B0 31 CD C1 D3 B3 37 B0 20 20 20 20 2F AD AD B0 37 31 B6
34 31 57 CD CB CB DA C2 C1 C1 0D 8A 31 B6 34 31 20 34 B9 32 83 B8 7E 7F
```

FF FF	envelope	*Arrange automatic ACARS forwarding*
...	message	[see above]

3.1 SATCOM Reliable Link Service

The Reliable Link Service (RLS) is a part of the AMS(R)S system which ensures that only whole and complete messages are forwarded on. The RLS achieves its *reliability* by cooperation of the Aeronautical Earth Station (AES) on the aircraft and GES to arrange for retransmitting individual missing parts. The RLS prepares the full message by chopping it up into smaller pieces. No new octets are added during the splitting.

There is space for **two octets** in the first part, then space for **eight octets** in the subsequent parts:

```
FF FF 01 32 AE B9 CD AD CD 52 4F 15 31 32 32 02 CD B0 32 C1 CD C8 B0 B3
37 B0 4F 46 46 B0 31 CD C1 D3 B3 37 B0 20 20 20 20 2F AD AD B0 37 31 B6
34 31 57 CD CB CB DA C2 C1 C1 0D 8A 31 B6 34 31 20 34 B9 32 83 B8 7E 7F
```

⇓ ⇓

1	FF FF	..
2	01 32 AE B9 CD AD CD 52	.2.9M-MR
3	4F 15 31 32 32 02 CD B0	O.122.M0
4	32 C1 CD C8 B0 B3 37 B0	2AMH0370
5	4F 46 46 B0 31 CD C1 D3	OFF01MAS
6	B3 37 B0 20 20 20 20 2F	370 /
7	AD AD B0 37 31 B6 34 31	--071641
8	57 CD CB CB DA C2 C1 C1	WMKKZBAA
9	0D 8A 31 B6 34 31 20 34	..1641 4
10	B9 32 83 B8 7E 7F	92.8..

Each of the ten parts will become a **Signalling Unit**. The complete set of the units will become a **Signalling Unit Set** .

3.2 SATCOM padding

All of the parts except for the first must be exactly eight octets in length. When the last part of the split message does not align exactly to the boundary, it must be *padded out* to the full width; zeros (00) are used. The number of genuine (non-padding) octets in the last part is recorded.

60 FF FF	`..
01 32 AE B9 CD AD CD 52	.2.9M-MR
4F 15 31 32 32 02 CD B0	O.122.M0
32 C1 CD C8 B0 B3 37 B0	2AMH0370
4F 46 46 B0 31 CD C1 D3	OFF01MAS
B3 37 B0 20 20 20 20 2F	370 /
AD AD B0 37 31 B6 34 31	--071641
57 CD CB CB DA C2 C1 C1	WMKKZBAA
0D 8A 31 B6 34 31 20 34	..1641 4
B9 32 83 B8 7E 7F 00 00	92.8....

60	length	*6* valid octets in last part
...	message	[see above]
00	padding	fill to end ($8 - 6 = 2 \times \mathit{padding}$)

3.3 SATCOM sequence and priority

To show that all of the parts belong to the same set, they are each given a sequence number (position) within the set, plus a shared identifier for the whole set and a shared prioritisation rating.

```
 1              7D 09 60 FF FF         }.`..
 2   8 7D  01 32 AE B9 CD AD CD 52   .}.2.9M-MR
 3   7 7D  4F 15 31 32 32 02 CD B0   .}O.122.MO
 4   6 7D  32 C1 CD C8 B0 B3 37 B0   .}2AMH0370
 5   5 7D  4F 46 46 B0 31 CD C1 D3   .}OFF01MAS
 6   4 7D  B3 37 B0 20 20 20 20 2F   .}370    /
 7   3 7D  AD AD B0 37 31 B6 34 31   .}--071641
 8   2 7D  57 CD CB CB DA C2 C1 C1   .}WMKKZBAA
 9   1 7D  0D 8A 31 B6 34 31 20 34   .}..1641 4
10   0 7D  B9 32 83 B8 7E 7F 00 00   .}92.8....
```

The priority and message set identifier both remain common to all of the parts, while the sequence number counts down to zero. A longer original message will use a starting sequence number which is higher. The last sequence number will always be zero.

9–0	sequence no	position in message (counting down)
D	grouping	Signalling set identifier (same across the set)
7	priority	*normal* priority (scale of 0–15)
...	message	[split parts from above]

3.4 SATCOM addressing

Every ACARS message sent over Satcom is re-broadcast to one-third of the whole the planet. Because of the number of listeners it is necessary to know precisely which GES the message is destined for, and whom the sender was.

The identities of the sender and destination are added to the first part of the set. The *from address* is the unique address of the AES onboard the aircraft. For 9M–MRO this is $75008F_{16}$. The *to address* is the unique address of the GES in Perth which is GES 305, or $C5_{16}$ in hexadecimal form:

```
  75  00 8F C5 7D 09 60 FF FF     u...}.`..
 8 7D  01 32 AE B9 CD AD CD 52   .}.2.9M-MR
 7 7D  4F 15 31 32 32 02 CD B0   .}O.122.MO
 6 7D  32 C1 CD C8 B0 B3 37 B0   .}2AMH0370
 5 7D  4F 46 46 B0 31 CD C1 D3   .}OFF01MAS
 4 7D  B3 37 B0 20 20 20 20 2F   .}370    /
 3 7D  AD AD B0 37 31 B6 34 31   .}--071641
 2 7D  57 CD CB CB DA C2 C1 C1   .}WMKKZBAA
 1 7D  0D 8A 31 B6 34 31 20 34   .}..1641 4
 0 7D  B9 32 83 B8 7E 7F 00 00   .}92.8....
```

75008F	source	AES ICAO 24-bit address for 9M–MRO
C5	destination	GES 305 at Perth
...	message	[see above]

3.5 SATCOM Signalling Unit type

Each Signalling Unit is prefixed by its type. Because the first part contains the address details and length information it is special, and is given a different Signalling Unit type to the remainder of the parts:

1	71 75	00 8F C5 7D 09 60 FF FF	qu...}.`..
2	C8 7D	01 32 AE B9 CD AD CD 52	.}.2.9M-MR
3	C7 7D	4F 15 31 32 32 02 CD B0	.}O.122.M0
4	C6 7D	32 C1 CD C8 B0 B3 37 B0	.}2AMH0370
5	C5 7D	4F 46 46 B0 31 CD C1 D3	.}OFF01MAS
6	C4 7D	B3 37 B0 20 20 20 20 2F	.}370 /
7	C3 7D	AD AD B0 37 31 B6 34 31	.}--071641
8	C2 7D	57 CD CB CB DA C2 C1 C1	.}WMKKZBAA
9	C1 7D	0D 8A 31 B6 34 31 20 34	.}..1641 4
10	C0 7D	B9 32 83 B8 7E 7F 00 00	.}92.8....

The parts can now be transmitted in any order because each part contains its group identifier as well as its position within the group. The type values are:

71	type	Initial Signalling Unit
C8-C0	type	Subsequent Signalling Unit (with sequence)

3.6 SATCOM Signalling Unit checksum

To ensure integrity for every individual part, an individual checksum is calculated for each Signalling Unit (SU) and included to make each Signalling Unit an equal length of twelve octets.

71 75	00 8F C5 7D 09 60 FF FF	19 15	qu...}.`....
C8 7D	01 32 AE B9 CD AD CD 52	B5 87	.}.2.9M-MR..
C7 7D	4F 15 31 32 32 02 CD B0	F2 28	.}O.122.M0.(
C6 7D	32 C1 CD C8 B0 B3 37 B0	72 CA	.}2AMH0370r.
C5 7D	4F 46 46 B0 31 CD C1 D3	BD 72	.}OFF01MAS.r
C4 7D	B3 37 B0 20 20 20 20 2F	D0 AA	.}370 /..
C3 7D	AD AD B0 37 31 B6 34 31	FB D0	.}--071641..
C2 7D	57 CD CB CB DA C2 C1 C1	BA 5F	.}WMKKZBAA._
C1 7D	0D 8A 31 B6 34 31 20 34	46 9A	.}..1641 4F.
C0 7D	B9 32 83 B8 7E 7F 00 00	12 2B	.}92.8.....+

For the Satcom error checking, a 16-bit Cyclic Redundancy Check is also used to produce the checksum contained within each Signalling Unit. The particular CRC16 variant used is called "CCITT" or "X.25" and starts with the value 65,535 (FF FF), before adding and multiplying the message values together.

...	message	[split parts from above]
NN-NN	checksum	calculated total of octets in each line

Even with all the wrapping that has taken place to encapsulate and prepare the message for transmission, we can still pick out the aircraft address, registration, callsign and flight numbers; plus the date/time, the fuel load. The Signalling Unit Set is now ready for transmission.

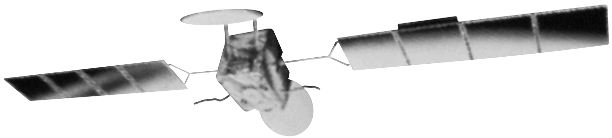

Figure 3: Inmarsat-3 spacecraft. (NASA PUBLIC DOMAIN)

4 Space segment

An Aeronautical Earth Station (AES) on-board the aircraft must follow the directions of the Ground Earth Station (GES) about when it can speak or transmit.[3]

At 16:41:53.405 the GES sent permission for the AES on-board 9M–MRO to be allowed to start transmitting in the next superframe. This frame was scheduled to begin a few seconds later at 16:41:57. The permitted frequency for transmission was given as a nominal 1646.6850 MHz, with a speed of 1,200 bits-per-seconds.

The transmitted signals left via one of three Satcom L-Band antennas on-board the aircraft[4] and $\frac{1}{8}$ second later were picked up by the Inmarsat 3-F1 spacecraft (1996-020A) in orbit, and relayed out again. The frequency converter on-board the spacecraft increases the frequencies, changing them from L–Band to C–Band (even higher). The L→C frequency converter increases the frequency of all transmission signals by the same amount, so an incoming signal at 1646.6850 MHz is rebroadcast at 3615.1850 MHz. The spacecraft operates as a "bent-pipe" and is not aware of the contents of the signals it is rebroadcasting.

5 Ground Earth Station

A further $\frac{1}{8}$ second later again the rebroadcast signals began to reach the Ground Earth Stations at Eik in Norway and Perth in Australia. Additional approximate Doppler compensations were made to the incoming signals from the spacecraft, the signal was down-converted and demodulated, and ultimately the Signalling Units were decoded. One SU arrived every ~160 milliseconds, with them being logged to the **Signalling Unit logfiles** as they went. It took 1.5 seconds for all ten SUs to arrive.

The information that is available to be logged can originate from different categories. The first are external observations of the transmission: the time, and frequency. Second are the house keeping information such as the Ocean Region that particular GES is handling. Third are measurements taken while attempting to decode the transmission such as the level of errors, received signal strength, and the frequency and timing offsets plus a record of which piece of equipment performed the decoding.

Fourth is the data itself, in its hexadecimal form. Fifth is duplication and highlighting of some of the received data for the ease of human reading. Those fields duplicated for human reading include the source and destination address, the Signalling Unit (SU) type field, priority and reference number; and the result of matching the address to a database to obtain the ACARS network provider (SITA) to replace the FF FF "envelope" for onwards delivery.

[3]Several additional layers of wrapping, error correction checksums, interleaving and prepending of training sentences and the addition of the $\texttt{E15AE893}_{16}$ magic word occur prior to T-Channel RF transmission. These lower-level processes are not reflected in the (higher-level) unredacted Signalling Unit logfiles and are intentionally omitted within this briefing for the sake of readability: the full specification is Part III of the AMS(R)S manual.

[4]Two side-mounted High-Gain Antennas (HGA) and one roof-mounted Low-Gain Antenna (LGA).

5.1 Signalling Unit log file comparisons

Figure 4 and 5 match the earlier OOOI take-off message to the Comma-Separated Value (CSV) print outs shown to CNN by Inmarsat on 23 May 2014 in the pages of unredacted SU log files. In Figure 5 the 3615.1850 MHz frequency[5] can be seen as 36FA in the *Channel Name* column.[6]

1	71	75	00	8F	C5	7D	09	60	FF	FF	19	15	qu...}.`....
2	C8	7D	01	32	AE	B9	CD	AD	CD	52	B5	87	.}.2.9M-MR..
3	C7	7D	4F	15	31	32	32	02	CD	B0	F2	28	.}O.122.MO.(
4	C6	7D	32	C1	CD	C8	B0	B3	37	B0	72	CA	.}2AMH0370r.
5	C5	7D	4F	46	46	B0	31	CD	C1	D3	BD	72	.}OFF01MAS.r
6	C4	7D	B3	37	B0	20	20	20	20	2F	D0	AA	.}370 /..
7	C3	7D	AD	AD	B0	37	31	B6	34	31	FB	D0	.}--071641..
8	C2	7D	57	CD	CB	CB	DA	C2	C1	C1	BA	5F	.}WMKKZBAA._
9	C1	7D	0D	8A	31	B6	34	31	20	34	46	9A	.}..1641 4F.
10	C0	7D	B9	32	83	B8	7E	7F	00	00	12	2B	.}92.8.....+

Figure 4: Unredacted Signalling Units 16:41:57.248 to 16:41:58.729. Highlighted numbers are flight/callsign, date/time, fuel. Lines start on the LEFT (71, C8, C7, ..., C0). Compare to Figure 5.

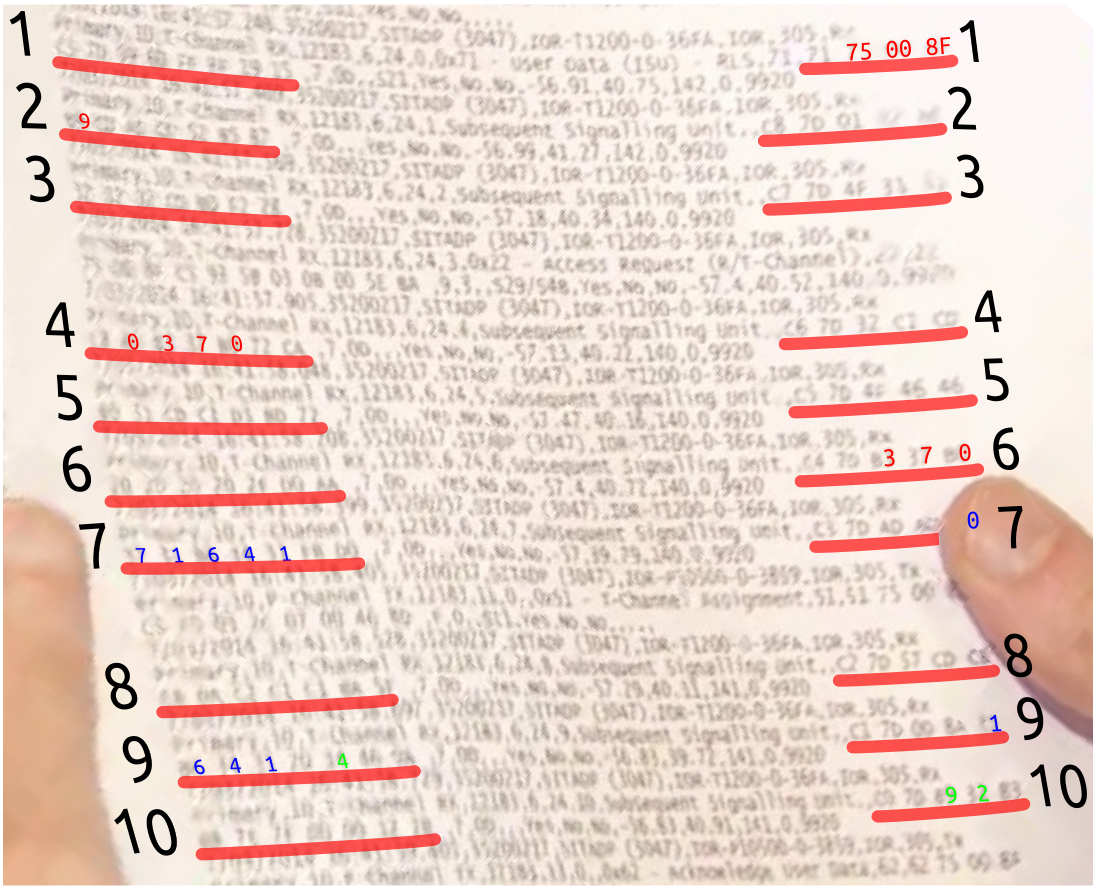

Figure 5: Unredacted Signalling Unit log 16:41:57.248 to 16:41:58.729. Highlighted numbers are flight/callsign, date/time, and fuel. Cross-reference with values in Figure 4. Highlighted hexadecimal user data lines start on the RIGHT (71, C8, C7, ..., C0) and wrap to LEFT side. (CNN)

[5] Nominal channel frequency. Doppler pre- and post-compensation discussion is omitted in this briefing note.

[6] $\texttt{hex}\left(\frac{3615.1850\,MHz\ input - 1968.5\,MHz\ spacecraft\_local\_oscillator_{LtoC} - 101.5\,MHz\ tx\_shift_{LtoL} - 1510.0\,MHz\ base}{0.0025\,MHz\ channel\_width}\right)$

Figure 6: Unredacted Signalling Unit log 16:42:23.039–16:42:25.909. Examples of fields that are present (Time, BFO, BTO, . . .) in Figure 7 verses other fields not present in the later Malaysian publication (Framing, Sequence, Received Signal Strength, . . .) (CNN)

7/03/2014 16:42:22.891	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	157	9940
7/03/2014 16:42:23.039	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	154	9940
7/03/2014 16:42:23.188	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	154	9940
7/03/2014 16:42:23.348	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	153	9940
7/03/2014 16:42:23.508	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	153	9940
7/03/2014 16:42:23.697	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	152	9940
7/03/2014 16:42:23.828	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	152	9940
7/03/2014 16:42:23.988	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	150	9940
7/03/2014 16:42:24.028	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	150	9940
7/03/2014 16:42:25.748	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	148	9940
7/03/2014 16:42:25.909	IOR-T1200-0-36D7	IOR	305	8	T-Channel RX	Subsequent Signalling Unit	148	9940

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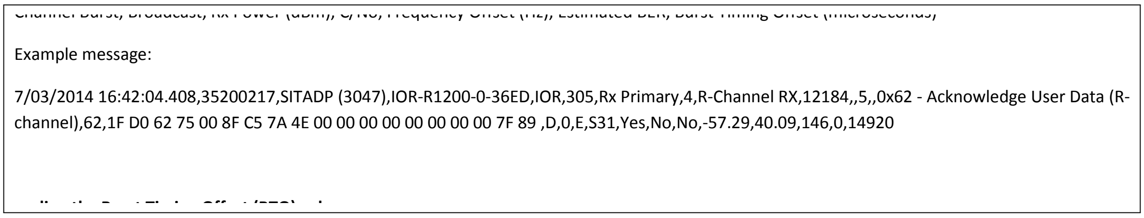
Figure 7: Redacted Signalling Unit log 16:42:23.039–16:42:25.909 from the Malaysian publication. Artifacts of manual preparation are apparent in the stepped misalignment of the first column verses remaining columns—visible at the cut-line. Match values with Figure 6. (MDCA)

Figure 8: Mark Dickinson showing various unredacted log file sections to CNN on 23 May 2014. CENTRE: 16:42:04.408 SU highlighted. LEFT: Mark Dickinson, at Inmarsat HQ. (CNN)



Example message:

7/03/2014 16:42:04.408,35200217,SITADP (3047),IOR-R1200-0-36ED,IOR,305,Rx Primary,4,R-Channel RX,12184,,5,,0x62 - Acknowledge User Data (R-channel),62,1F D0 62 75 00 8F C5 7A 4E 00 00 00 00 00 00 00 00 7F 89 ,D,0,E,S31,Yes,No,No,-57.29,40.09,146,0,14920

Figure 9: Later Malaysian Department of Civil Aviation publication with 16:42:04.408 example given on Page 1 only. Cross-checked for validity with previously obtained Figure 10. (MDCA)

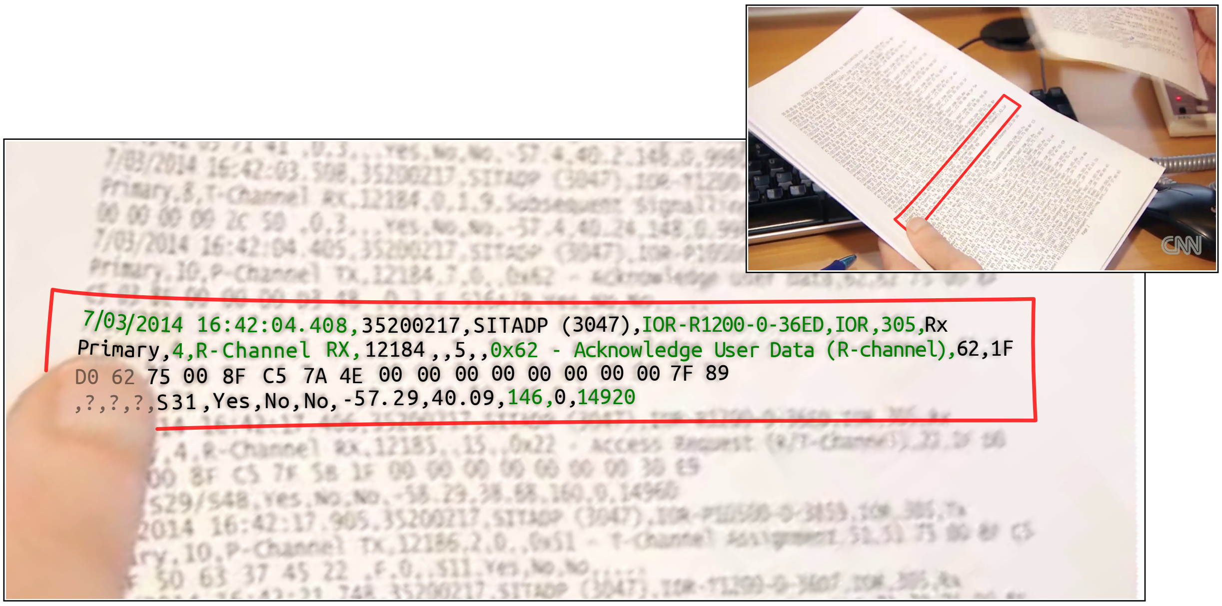


Figure 10: Unredacted Signalling Unit log example with 16:42:04.408 highlighted. Only those fields highlighted are present in the main body of the later Malaysian release. (CNN)

Figure 11: Mark Dickinson showing log field-headings to CNN on 23 May 2014.
LEFT: Unredacted field headings. RIGHT: Mark Dickinson, at Inmarsat HQ. (CNN)

Field Headings:

Time, AES ID, DP AES Owner, Channel Name, Ocean Region, GES ID (octal), Channel Bearer, Channel Unit ID, Channel Type, Superframe Number, Frame Number, Slot Number, SU Number, SU Type, SU Type Code, SU Contents, Q Number, Reference Number, Ack Control, SDM Figure, CRC Correct, Missed T-Channel Burst, Broadcast, Rx Power (dBm), C/No, Frequency Offset (Hz), Estimated BER, Burst Timing Offset (microseconds)

Figure 12: Later Malaysian Department of Civil Aviation publication with unredacted example headings on Page 1 only. Cross-checked for validity with previously obtained Figure 13. (MDCA)

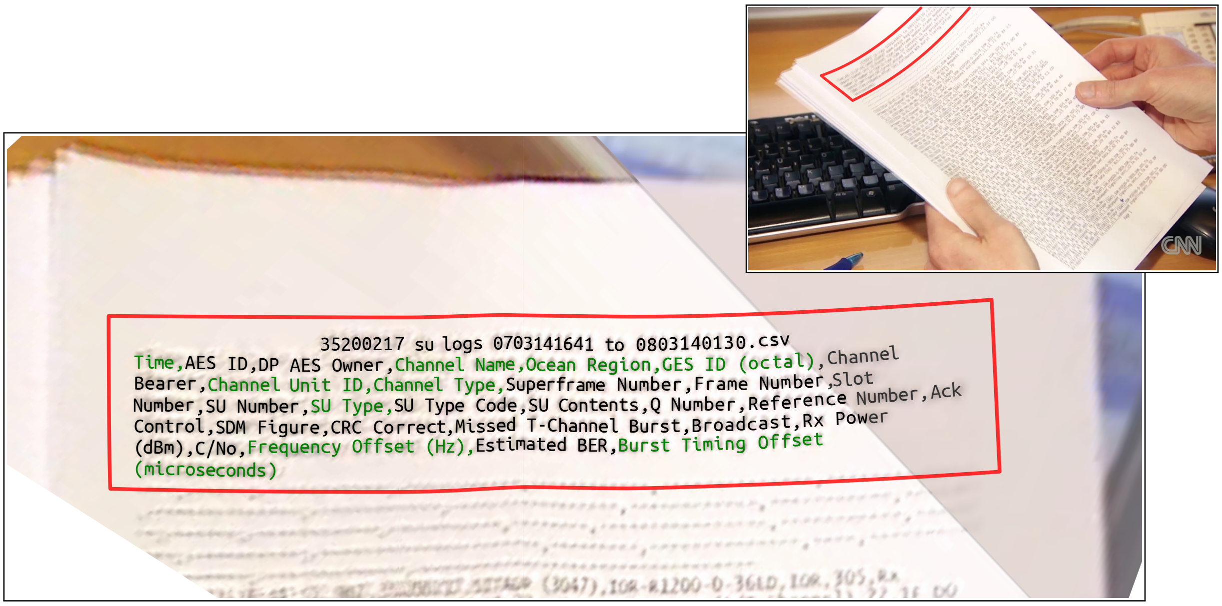


Figure 13: Unredacted Signalling Unit log field-headings. Only those highlighted fields were present in the main body of the later Malaysian release. (CNN)

Conclusion

We have traced how a simple OOOI take-off message is wrapped up in preparation for transmission by ACARS and Satcom. We have identified this complete message in the logged Signalling Units of the unredacted logs publicised by Inmarsat (Figure 5). We have observed that the same content is not present in the later Malaysian Department of Civil Aviation publication and deduced redaction of 19 out of 28 columns in the later Malaysian publication of 27 May 2014.

In line with other safety-of-life systems, *Classic Aero* Satcom messages are transmitted in the clear and by their nature are rebroadcast to one-third of the planet in both directions. Such communications can not in anyway be regarded as "secret" or "confidential"[7] and this appears to have been reflected in Inmarsat's actions and statements.

List of Terms

9M–MRO	Malaysian Boeing 777-2H6/ER aircraft cn. 28420. 1, 7, 9
1996-020A	Inmarsat 3-F1 spacecraft. 9, 14
$75008F_{16}$	International Civil Aviation Organization 24-bit address $75008F_{16}$. 7
AAIB	Air Accident Investigation Branch. 1
ACARS	Aircraft Communications Addressing and Reporting System. 2, 3, 5, 9, 14, 15
AES	Aeronautical Earth Station. 6, 7, 9
AMS(R)S	Aeronautical Mobile Satellite (on-Route) Service. 5, 6, 15
CRC16	16-bit Cyclic Redundancy Check. 5, 8
CSV	Comma-Separated Value. 10
FMC	Flight Management Computer. 2
GCHQ	Government Communications Headquarters. 14
GES	Ground Earth Station. 3, 5–7, 9, 14
$C5_{16}$	GES $C5_{16}$ in Perth. 7
GES 305	Ground Earth Station 305_8 at Perth. 7
IATA	International Air Transport Association. 3
ICAO	International Civil Aviation Organization. 3, 7, 14
ISU	Initial Signalling Unit. 8
MCDU	Multifunction Control Display Unit. 2
MDCA	Malaysian Department of Civil Aviation. 1, 11–14
OOOI	Out Off On In. 2, 3, 10, 14
RADAR	RAdio Detection And Ranging. 2
RLS	Reliable Link Service. 6
SAT	Satellite. 2
SDU	Satellite Data Unit. 5
SU	Signalling Unit. 8–14

[7] With regard to 1996-020A the well-known 106.5° azimuth of the antennæ at GCHQ Bude is tangentially noted.

Contents

Tables, Figures & Datasets

Multiple frames and angles were used for dewarping. Data values found obscured or unreadable were recovered using the two-layers of CRC16 checksums present (Kermit & X.25)[8] to facilitate user-data error correction and recovery, in a similar manner to solving a giant Sudoko grid.

8 ACARS "Kermit" `crc_algorithms.Crc(width=16, poly=0x1021, reflect_in=True, xor_in=0x0000, reflect_out=True, xor_out=0x0000)`
AMS(R)S "X.25" `crc_algorithms.Crc(width=16, poly=0x1021, reflect_in=True, xor_in=0xffff, reflect_out=True, xor_out=0xffff)`