Analysis of the radar data at Kota Bharu and at Penang Island

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Version 2.0 - 6 March 2023 – Updated 26 March 2023

Executive Summary:

A simple analysis of the speed is presented using the civil radar data sets of the flight around Kota Bharu and Penang Island provided by the IG. The question to answer is whether this data is of sufficient quality to allow a precise estimation of the instantaneous aircraft speed after the U-Turn at IGARI and until Pulau Perak Island up to 10 Nm after MEKAR at 18h12:22.

The study considered the average speed computed for each available radar segment by using the 1st echo and last echo time tags and the distance flown.

After considering these average speeds and Mach at ~FL384 (i.e. true height 40500ft) and subsequently at ~FL300 (true height 31500ft), the following conclusions were drawn:

1. There is a quasi-permanent situation of overspeed at Mach 0.88 (in average)
2. FL384 is well above the maximum level for the detection of a mobile phone at Penang
3. At FL300, the Mach is constantly within the flight envelope
4. But for both, the slow speed between the Exit point of the U-Turn after IGARI and the 1st echo location appears unrealistic especially at FL384 which is at the minimum speed of manoeuvrability.

Based on this, the time tags of the radar data appear erratic and should not be used to estimate the speed locally as the speed estimation from these data would appear not to be made on solid ground

Thus, for the time being, the most reasonable estimation of the ground speed is based on using the three well known points overflown by the aircraft and their time tags. Subsequently, the airmen's way to compute the distance/time between the exit point of the U-Turn at IGARI, the location of the detection of the co-pilot's mobile phone and the location at 10Nm after MEKAR provides us with two very close average speeds. This provides a usable average ground speed of ~506kt all the way long.

1 Introduction

In 2018 and later in early 2019, radar data were kindly made available by M. Exner (of the IG) on V. Iannello's web site. This data is described as originating from civilian approach radars at Kota Barhu and at ButterWorth in Malaysia. (cf mh370.radiantphysics.com on 11 April 2018 page).

From this data, some initial observations and some computations have been made by several people. Some were very detailed like the post on VI's the blog, the UBIG report, the paper "Deriving MH370 altitude and Speed profile for January 2019 data" (Mike Exner 2019/03/13), from Paul Smithson etc ...

Nevertheless, a question remains: can this data be used to estimate the aircraft speed along the path covered by this data. In the official Malaysian report, it is stated that the data geographically matches well the military track but it is underlined that the time tags were very noisy.

Starting from this last observation and from a visible asymmetry of the plot track on GoogleEarth and on distance measurements, a simple geometrical analysis of the radar data raises the question whether it is reliable plot data from civilian radars or if it is tracks data. This would have an impact on using it or not for further speed computation.

2 Analysis of the segment at the Exit of the U-Turn after IGARI

Before analysing the radar data, one piece of information is directly available to characterise the leg between the Exit point of the U-Turn after IGARI and the 1st available radar echo. Their respective timing and the flown distance between these two points provide interesting results as posted in Table 1.

Table 1: Timings between the Exit of the U-Turn and the Excel data for KB subset 1 (True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
Official Report & KB-1 Excel	17:24:40 U-Turn Exit official	17:30:34.98 1st Radar echo	05:54.98	45.0	457	0.75

The measured distance between the Exit point of the U-Turn and the 1st radar echo provided in the Excel file leads to an average TAS (True Air Speed) of 445kt taking into account the local meteorological conditions. The GDAS data reports a wind at max 13kt at 81°. This translates into an Indicated Air Speed of 241kt. If we would use the radiosonde data at Kota Bharu it would mean an IAS of 235kt which is under the recommended manoeuvring speed of 241kt.

Considering the mass of the aircraft and the flight level (FL384), this average IAS is just at the recommended holding speed to provide adequate buffet margin above FL250 i.e. Vref 30 + 100. This translates into 141 + 100 = 241kt for 216t.

Conclusion:

Table 2: Summary of the average Mach in the gap between the two radar coverages at True Heigh 40500ft i.e. FL384

Segment	Average TAS (kt)	Evaluation
Exit point of the U-Turn -> 1st radar echo	235/241	*Too low, just equal to and possibly below (in average) the recommended holding speed of 241kt*

3 Analysis of the data at Kota-Bharu

The geometrical analysis starts by a quick review of the available information concerning the radar tracks. Then a visual inspection of the distance indicated by the provided data with respect to the radar maximum coverage range and to the cone of silence around the approach radar at Kota Bharu located at [N6.1636°;E102.2938°] is performed.

3.1 Data set

The Excel data file includes two subsets of data around Kota Bharu i.e. 98 triplets and 79 triplets respectively. Each triplet includes the time tag with 3 decimal digits, the slant range distance between the sensor head and the target in Nm with 5 decimal digits and the absolute azimuth of this vector in degrees with 7 decimal digits.

The SELEX ATCR-33 DPC radar specifications post a target accuracy of 50m in slant range and 0.16° in azimuth. Thus, a first remark concerns the number of decimal digits. Considering the accuracy, the data should have been rounded to the closest 3rd decimal digit for the range and to the closest 2nd decimal digit for the azimuth.

Let's compare the information from the Excel file with the official information published so far. The Malaysian Report [1] provides also two sources of timing information recorded by the AAT systems at the very same site of Kota Bharu.

Segment towards Kota Bharu

The first Subset provides data covering the segment from the location where the aircraft entered the radar coverage until it entered the cone of silence. Table 3 summarises the different data on the times tags of the first recorded information and of the last recorded information.

It should be noted that the official report charts 1.1F and 1.1G from Selex do not provide any speed or altitude indication. This is because SSR data are not available and because of the inherent poor quality of the PSR data.

Table 3: Comparison between the official timings and the Excel data for KB subset 1 (to KB, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
KB-1 Excel	17:30:34.98	17:36:44.74	06:09.77	51.5	501	0.83
KB-1 P1778	17:30:33.14	17:36:50.32 (not last)	06:17:18	n/a		
KB-1 P3362	17:30:37	17:37:12	06:35:00	n/a		
KB-2 Excel	Great circle from 1st echo to last echo			50.2	489	

The immediate conclusion coming from the Delta Time column in Table 3 is that the Excel file includes fewer data than was actually available because its time interval is shorter than the other official data sets. In addition, the drawing of P1778 in the Malaysian report [1] shows a longer track entering the CoS with a bigger turn that the Excel file data shows.

Under the weather conditions at this true height with the radiosonde meteo, the average ground speed of 501kt means a TAS equal to 479kt thus a Mach of 0.83. On that leg, the speed value does not raise any concern.

Cone of Silence

Obviously, in between the two subsets of data, there no information inside the CoS. Nevertheless, the entry and exit times are known as presented in Table 4 and the great circle distance is used which represents the shortest distance between them.

Table 4: Comparison between the official timings and the Excel data for KB Cone of Silence (True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
KB-2 Excel	17:36:44.74	17:38:55.68	02:10.94	19.3	531	0.89
P1778->P1793	17:36:50.32	17:38:55.00	02:04.68	n/a		
KB-2 P3401	17:37:12	17:38:56	01:46:00	n/a		

By itself, the computed average ground speed of 531kt is not credible as it means a TAS of ~510kt leading to a Mach at 0.89 in using the meteo report from the radiosonde and GDAS. Even in considering a +/- 5kt margin in the computations, the lower speed would still be above the Mach limit of 0.87. Thus, this places serious doubts on the quality of the data sets. As it is an average it means that either the aircraft flew faster during some time or the speed during the adjacent legs is affected. As the location of the tracks appear to be correlated with the military ones, it is logical to conclude that the data time tags suffered either a shift or a drift or both.

Segment out of Kota Bharu

Table 5 present the information available for the 2nd subset of data concerning the path of the aircraft going away from the radar after exiting the cone of Silence (CoS).

Table 5: Comparison between the official timings and the Excel data for KB subset 2 (out of KB, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
KB-2 Excel	17:38:55.68	17:44:24.00	05:28.32	50.0	548	0.91
KB-2 P1793	17:38:55.00	n/a		n/a		
KB-2 P3401	17:38:56	17:44:42	05:46:00	n/a		
KB-2 Excel	Great circle from 1st echo to last echo		05:28.32	48.36	530	0.89

The computed average ground speed of 548kt means a TAS at about 525kt when taking the radiosonde meteo and 534kt with GDAS wind at 72° (14kt). This means an average Mach of 0.91. When taking the shortest distance between the 1st echo and the last one, the average Mach is 0.89. Both results are not realistic. The same conclusion can be drawn as above for the previous subsets. Even in considering a +/- 5kt margin in the computations, the lower speed would still be above the Mach limit of 0.87.

Conclusions

According to Table 6, the two segments well above Mach 0.87 in average means that the piloting was necessarily manual during a non negligeable time to stay at that speed for the full duration of the concerned segments or at an even higher speed but for shorter times. This means that manual counteractions took place against the automation. When above M0.87 the automation of the aircraft takes actions to reduce the auto throttle setting or/and to pitch up the aircraft to slow it down. Thus, to maintain an average speed above M0.87 the pilot must "fight" against the automation in manually pushing the throttle and pushing forward heavily the control column … this is manual piloting.

Table 6: Summary of the speeds within Kota Bharu radar coverage at True Heigh 40500ft i.e. FL384

Segment	Ground speed (kt)	Mach	Distance (Nm)	Data availability
1	501	0.83	51.5	Radar data
2	*531*	*0.89*	*19.3*	*CoS*
3	548	0.91	50.0	Radar data
Overall	529	0.88	120.8	

3.2 Geometrical analysis

Figure 1 illustrates the different circles centred on Kota Bharu sensor head/antenna. The orange circles pass by the 1st echo of the Excel file KB subset 1 and the last echo of the KB subset 2. The red circles pass by the last echo of subset 1 and by the 1st echo of subset 2, they are opposite on the boundary of the cone of silence.

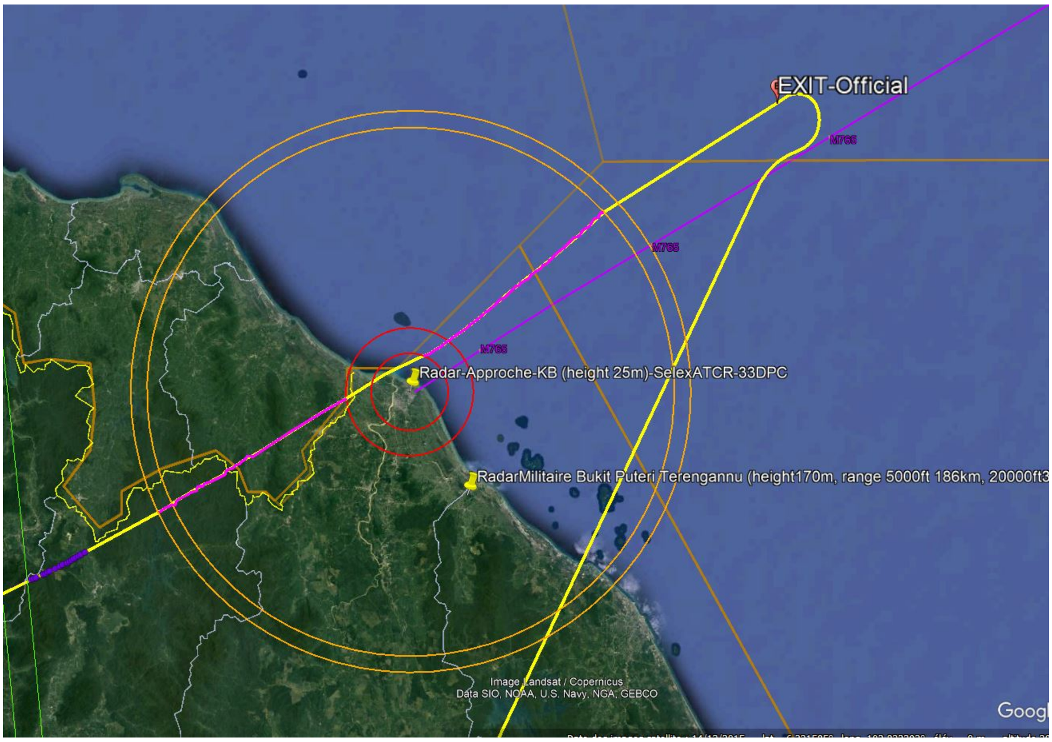

Figure 1: KB data compared with the range (Orange) and the cone of Silence (Red)

In the absence of mountains in the vicinity (at least within 65Nm), the system should be perfectly circularly symmetrical and the expectation is that only 1 orange circle should be visible for the range as well as 1 red circle for the CoS.

But it is visible that the 1st echo in the north-east and last Echo in the south-west in KB coverage range do not lay on the same orange range circle. Considering the aircraft at a true height of 40500ft, the 1st echo is at a distance of 57.5Nm from the radar while the last echo is at 61.2Nm. Note that 57.5Nm is shorter than the supposed 60Nm range capability. The difference in range is 3.7Nm without any obvious reason especially when considering that the shortest range is on the sea and thus with no obstacle. The 3.7Nm difference represents 5.2%.

The same visible conclusion is made for the cone of silence (CoS) at KB. The entry echo is at 8.3Nm from the Approach radar antenna while the exit echo is located at 14.0Nm. The difference is 5.7Nm which means ~50% difference. The fact that they do not lay on the same red circle is not as expected from a circular symmetrical radar system.

These results are summarised in Table 7 that the Approach radar at Kota Bharu airport is located at [N6.1636°;E102.2938°]. The data do not show circular symmetry.

Table 7: Distance of min/max echoes for Approach radar at KB (Aircraft at True height 40500ft)

Approach radar at KB Airport	***Distance (Nm)***	***Difference***	***Relative diff. to shortest***	***Elevation at CoS boundary***
1st echo in radar Coverage	57.5			-
Last echo in radar coverage	61.2	3.7Nm	5.2%	-
1st echo in CoS	8.3			38.8°
Last echo in CoS	14.0	5.7	69%	25.5°

In addition, when considering the antenna diagram, there is a mismatch with the measured elevation angles at the entry and at the exit of the Cos i.e. 38.8° and 25.5° respectively with the antenna capability around 43° at true height of 40500ft as shown in Figure 2 and illustrated by the green circle in Figure 3. This means that the available track should have been 2 Nm longer at the entry i.e. ~3 radar echoes are missing. At the exit of the CoS and taking into account the same 2Nm latency measured at the entry in the coverage for the tracker to confidently starts a new track, this means that ~10 radar echoes are missing on the available track after the CoS. This is unexpected as the backscatter cross-section is favourable in this overflying configuration. Figure 2 diagram is given for a 2m^2 Radar Cross Section (RCS) which is typical for a general aviation aircraft. A typical large airliner RCS is usually several tens of m^2 depending on its orientation and thus should lead to a higher elevation of the (smaller) CoS. An Airbus A320 aircraft posts an RCS of ~100 m^2 for example and the B77 RCS is around ~200 m^2. In addition, the radar specifications indicate a target accuracy of 50m in range and 0.16° in azimuth. The latter raises questions when compared to the ButterWorth NEC radar accuracy of 1.5°.

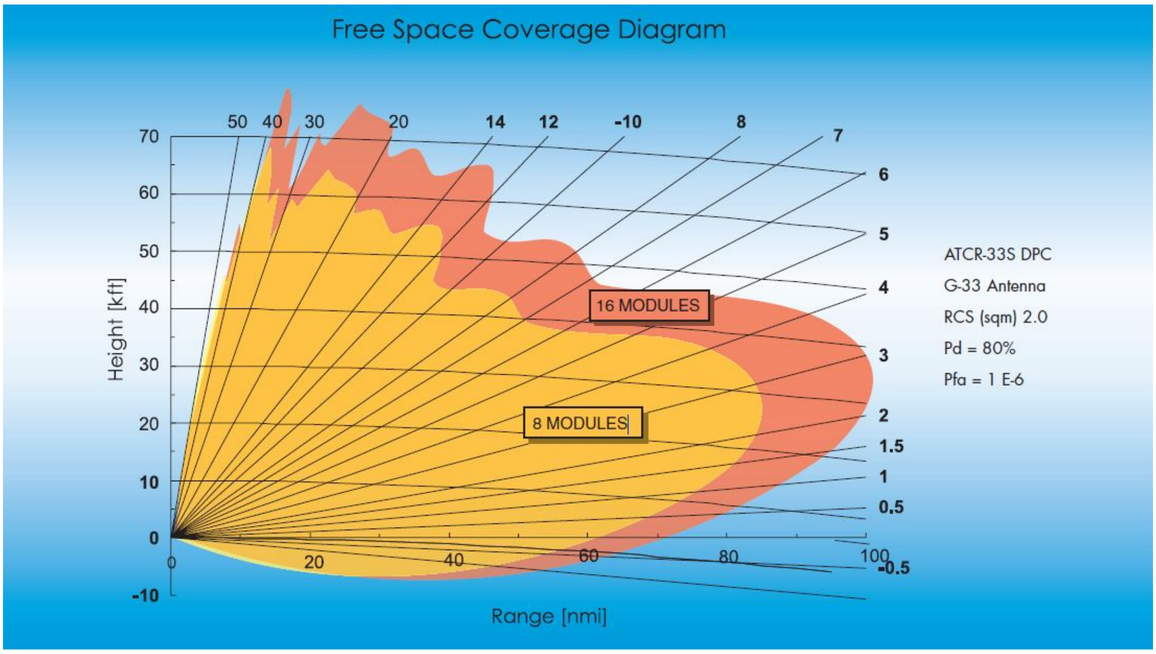

Figure 2: ATCR-33 DPC radar antenna diagram at Kota Bharu

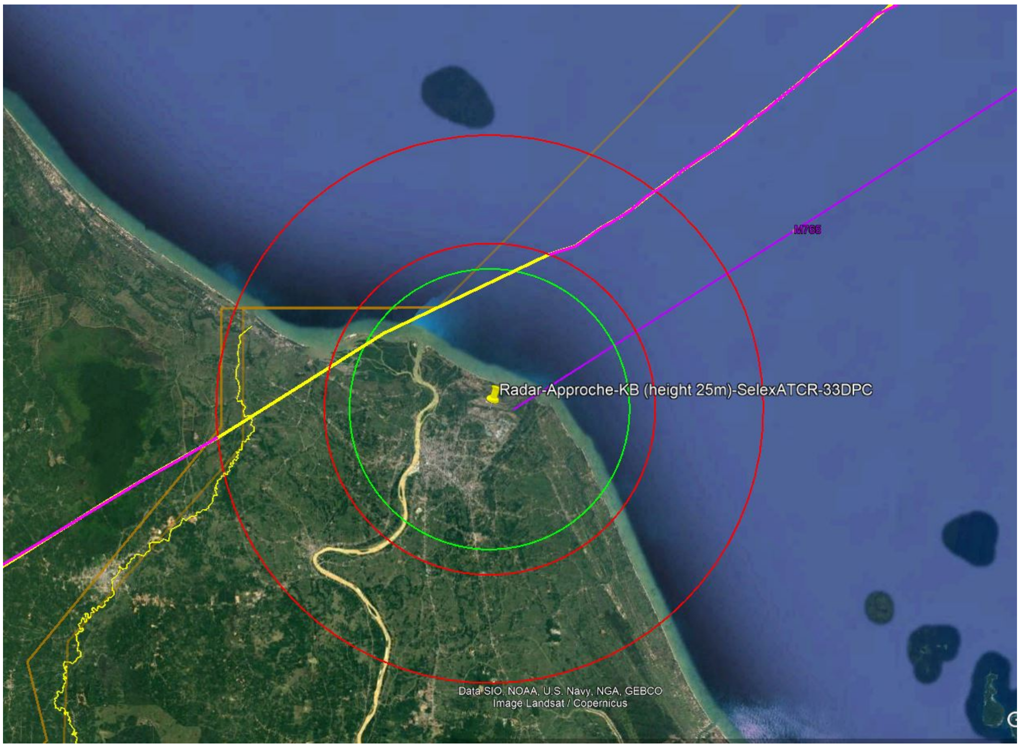

Figure 3: Cone of Silence of 43° elevation at 40500ft of the ATCR-33DCP at Kota Bharu (Green circle)

Normally genuine data acquired at KB by the approach radar sensor and provided as plot data should give us a full set of data matching the capability of the radar without missing echoes at boundaries.

Accepting that the echoes (plots) have been actually acquired at KB and as the data is missing some of them, then it means that they have been selected ("without additional processing to that inherent in the acquisition process" quote from the IG) via a tracking decision maker (or alike) which necessarily created a new "modified" data set without any SSR second source of data which increases the tracker precision. This could be easily verified in the ASTERIX header of the data thanks to the CAT value which is not communicated at this stage for protecting the data provider.

In a previous version of this paper, it was envisaged that the Military radar located at Bukit Puteri, Terengannu i.e. at [N5.7858°;E102.5044°] could bring a "circular symmetrical reality". But this did not pass the scrutinising review especially the geometry of its CoS.

3.3 Conclusions

The data made available by the IG presents the characteristics of "track" data in the ASTERIX sense as opposed to "plot" data. Compared with the SELEX radar manufacturer official data posted in the Malaysain report [1], the recorded data shows numerous differences in the time tags.

In addition, while the average Mach number is within the flight envelope during the first radar segment towards Kota Bharu, the computed average speeds during the cone of silence and the during the segment going out of Kota Bharu show values well above the maximum flyable Mach 0.870. Consequently, it is logical to consider that the provided data in the Excel file raises an issue. As the geographical locations have been recognised fitting the military data, one should question the time tags assigned to the data.

It is also logical to consider that a data selection was made (may be slightly processed?) by a tracker - or alike - and thus was unavoidably modified during the track records creation at the minimum. In addition, a human intervention had to be necessary to construct the coherent set out of the different tracks as the machine did not recognised the segments as coming back from a unique aircraft. This introduced a subjective aspect in the data. In the Malaysian report, it is visible that the system identified two separate tracks i.e. P1778 (P3362) and then P1793 (P3401). They have been necessarily linked by somebody to make them a track.

This means that this "track" data cannot be considered as reliable for its time tags, thus it should not be used for speed or altitude computation without a second source of measurement. In absence of SSR data, ATC experts have confirmed that they avoid doing so when presenting the results on the controller's screen.

To be convinced about the time tags issue, Table 8 presents the reported time of the first echo considered for each data subset and its corresponding echo given in the Excel file.

Table 8: Comparison of the 1st echo of the different published data subset

Data Subset	1st echo time tag	Source		Comment
P1778	17:30:33.14	Fig 1.1F [1]	Plot (?)	
P1778	17:30:37.02	Fig 1.1G [1]	Track (?)	
KB-1	17:30:34.98	Excel File	???	Misses at least 1 echo
P1793	17:41:00.82	Fig 1.1F [1]	Plot (?)	How could plot data be available later than the track data?
P1793	17:38:56.98	Fig 1.1G [1]	Track (?)	
KB-2	17:38:55.68	Excel File	???	Mismatch with the supposed plot data

In report [1], it should be noted that in Fig 1.1C in the Malaysian report [1] only the tracks time tags are considered.

Table 9 summarises the evaluation of the computed average Mach when the aircraft was inside the KB radar area at FL384.

Table 9: Summary of the average Mach within Kota Bharu radar coverage at True Heigh 40500ft i.e. FL384

Segment	Average Mach	Evaluation
KB-1	0.85	Acceptable
KB-2	>0.90	Overspeed
KB-3	0.92	Overspeed
Overall	0.89	Overspeed

As concluded in the previous section, when the speed goes above M0.870 the automation of the aircraft takes actions to reduce the auto throttle setting or/and to pitch up the aircraft to slow it down. Thus, to maintain an average speed above M0.870 the pilot must “fight” against the automation in manually pushing the throttle and pushing forward heavily the control column … this is manual piloting.

4 Coverage gap between Kota Bharu and ButterWorth

By construction and by default, between the last subset of data at Kota Bharu and the first subset concerning ButterWorth, an area is not covered by any of these two radars. Thus, no information is available inside this area. Nevertheless, the entry and exit times are known as presented in Table 10.

Table 10: Comparison between the official timings and the Excel data in the in-between area (True height 40500ft)

Subset	Start Time	End Time	Delta Time	Distance (Nm)	Average Ground Speed (kt)	Mach
KB->BW Excel	17:44:24.00	17:46:22.53	01:58.53	17.2	523	0.88
P1793->P1805	n/a	17:47:01.62	n/a			
P3401->P3415	17:44:42	17:47:02	02:20.00	n/a		

The computed average ground speed of 523kt means a TAS of ~509kt wind at 72° and 14kt as given by GDAS. This leads to an average Mach of 0.88 above the maximum operating Mach.

As stated in the CoS analysis, it questions the quality of the data sets. As it is an average ground speed value it means that either the aircraft flew faster during some time or the speed in the adjacent legs must be reconsidered in accordance. As the location of the tracks appear to be correlated with the military ones, it is logical to conclude that the data time tags suffered either a shift or a drift or both.

Conclusion:

Table 11: Summary of the average Mach in the gap between the two radar coverages at True Heigh 40500ft i.e. FL384

Segment	Average Mach	Evaluation
Gap KB->BW	0.88	*Overspeed*

The same conclusion on the “pilot fighting against the aircraft automation” applies here as an average Mach above 0.870 means that the automation will do its most to slow down the aircraft below this limit. Thus, if this was true, the pilot would have manually flown this segment.

5 Analysis of the data at ButterWorth (Under update)

As for KB, the geometrical analysis starts by a quick review of the available information concerning the radar tracks. Then a visual inspection of the distance indicated by the provided data with respect to the radar maximum coverage range is performed. The radar sensor is located at [N5.4721°;E100.3947°].

Important*: there is no cone of silence around ButterWorth making this analysis different from the one for the approach radar at Kota Bharu. But the data is presenting numerous gaps in the track.*

According to GDAS via Nullshool, the meteo conditions are considered relatively stable, thus the wind magnitude is taken at 17kt with a direction at 73° and is adjusted time to time when necessary.

5.1 Data set

The Excel data file includes 6 subsets of data around ButterWorth in the south of Penang and of Western Hill including 19, 2, 8, 44, 4 and 13 triplets respectively.

The NEC ASR (airport Surveillance Radar) specifications post a target accuracy of 150m in slant range and 1.5° in azimuth. This accuracy is worse than KB's ASR. In fact, its azimuth accuracy is one order of magnitude lower.

In addition, considering the location of the echo posting the maximum range which is about 75Nm from the radar sensor and the presence of echoes at the closest distance, it is concluded that the NEC Airport Surveillance Radar (ASR) is most likely the most powerful model available. This means a typical range of 80Nm up to 45,000ft. This is further detailed in section 5.2 below.

<u>Segment 1 BW subset-1</u>

Subset 1 includes 19 triplets which are not separated in time by regular intervals. Four intervals post a measured duration of ~8s and two post ~12s. This means that 8 echoes are missing which represent more than 30% of the total number of potential echoes to be received.

Table 12: Comparison between the official timings and the Excel data for BW subset 1 (towards BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-1 Excel	17:46:23.00	17:48:06.77	01:43.77	15.4	533	0.90
BW-1 P1805	17:47:01.62	n/a	n/a	n/a		
BW-1 P3415	17:47:02	17:48:29	01:27:00	n/a		
BW-1 Excel	Great circle from 1st echo to last echo		01:43.77	15.3	531	0.89

The immediate conclusion coming from the Delta Time column in Table 12 is that the Excel file includes more data than is actually reported by the other official data sets in the report [1].

The computed average ground speed of 533kt means a TAS at about 518kt. This means an average Mach of 0.90. Both results are not realistic. The same conclusion can be drawn as above for the previous subsets. Even in considering a +/- 5kt margin in the computations, the lower speed would still be above the Mach limit of 0.87.

Segment 2 gap between BW subset-1 and BW Subset-2

The gap between the last echo of subset 1 and the first one of subset 2 is characterised by the following data presented in Table 13.

Table 13: Characteristics of the segment between Excel data BW-Subset 1 and BW-subset 2 (True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-2 Excel	17:48:06.77	17:49:50.85	10:59.84	15.4	534	0.89

The computed average ground speed of 534kt means a TAS at about 519kt. This means an average Mach of 0.89. Both results are not realistic. The same conclusion can be drawn as above for the previous subsets. Even in considering a +/- 5kt margin in the computations, the lower speed would still be above the Mach limit of 0.87.

Segment 3 - BW Subset2

The second subset includes 2 echoes only.

Table 14: Flight characteristics on the segment covered by BW-subset 2 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-2 Excel	17:49:50.85	17:49:54.91	00:4.06	0.61	540	0.90

This corresponds to a TAS of 525 kt. The average Mach is 0.91 thus well above 0.87. The fact that only 2 samples are available lowers the confidence in this measurement.

Segment 4 gap between BW subset-2 and BW Subset-3

The wind has slightly changed and will be taken care of.

Table 15: Flight characteristics on the segment of the gap between BW subsets 2 & 3 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-2-3 Excel	17:49:54.91	17:51:23.24	01:28.34	13.1	532	0.89

At these times, in this area and that altitude, and according to Nullschool, the wind has slightly increased to 17kt at ~71°.

This corresponds to a TAS of 515 kt. The average Mach of 0.89 thus again well above the flight envelope limit of 0.87.

Segment 5 - BW Subset3

Data Subset 3 includes 8 elements. It forms a small path crossing the coast line in the East/SouthEast of Penang Island. At the end, its misses 3 echoes due to the last time interval which is ~16s.

Table 16: Comparison between the official timings and the Excel data for BW subset 3 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-3 Excel	17:51:23.24	17:52:03.45	00:40.20	6.2	555	0.93
BW-3 P1812	17:51:44.38	n/a	n/a	n/a		
BW-3 P3426	17:51:45	17:52:25	00:40.00	n/a		

This corresponds to a TAS of 538 kt. The average Mach of 0.93 is well above 0.87 and is not realistic.

Segment 6 gap between BW subset-3 and BW Subset-4

Between Subset 3 and subset 4 the time interval is about 50 seconds. The aircraft was flying above the sea in the South of the Penang Island.

At these time, location and altitude, and according to Nullschool, the wind was at 17kt coming from ~71°.

Table 17: Flight characteristics on the segment of the gap between BW subsets 3 & 4 (south of BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-3-4 Excel	17:52:03.45	17:52:52.00	00:48.56	6.7	497	0.83

This corresponds to a TAS of ~480 kt. The computed average Mach is significantly lower at 0.83.

Segment 7 - BW Subset4

Data Subset 4 includes 44 elements. It includes the turn from the northeast to the northwest during the flyby in the south of Penang Island. A detailed review of the time intervals between the samples shows that 7 of them are 12s long while 10 are 8s long. This means that 24 echoes are missing which represent 35% of the total number of potential echoes to be received.

At these time, location and altitude, and according to Nullschool the wind was steady 17kt at ~70°.

Table 18: Comparison between the official timings and the Excel data for BW subset 3 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-4 Excel	17:52:52.00	17:57:22.84	04:30.84	38.5	512	0.86
BW-3 P3426	17:51:45	17:52:25	00:40.00	n/a		

This corresponds to a TAS of ~499 kt. The average Mach is just below the flight envelope limit of 0.87.

Segment 8 gap between BW subset-4 and BW Subset-5

Between Subset 4 and subset 5 the time interval is a little more than 1 minute. The aircraft is flying above the sea in the west of the Penang Island.

Table 19: Flight characteristics on the segment of the gap between BW subsets 4 & 5 (from BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-4-5 Excel	17:57:22.84	17:58:30.99	01:08.16	9.5	502	0.85

This corresponds to a TAS of ~490 kt. The average Mach is at 0.85.

Segment 9 - BW Subset 5

Data Subset 5 includes 4 elements. A detailed review of the time interval between the samples shows that 1 of them is 12s long. This means that 2 echoes are missing which represent 33% of the total number of potential echoes to be received

At these time, location and altitude, and according to Nullschool, the wind had slightly decreased to 13kt at ~72°.

Table 20: Flight characteristics from Excel data for BW subset 5 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-5 Excel	17:58:30.99	17:58:51.02	00:20.02	3.14	565	0.96
BW-5 Excel	Great circle from 1st echo to last echo		00:20.02	3.13	562	0.95

This corresponds to a TAS of ~555 kt or 552 kt in direct path. The average Mach is 0.96 which is unrealistically well above the flight envelope limit of 0.87.

Segment 10 gap between BW subset-5 and BW Subset-6

Between Subset 5 and subset 6 the time interval is a little less than 1 minute. The aircraft is still flying above the sea in the west of the Penang Island en route to VAMPI.

Table 21: Flight characteristics on the segment of the gap between BW subsets 5 & 6 (from BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-5-6 Excel	17:58:51.02	17:59:47.00	00:55.98	7.7	494	0.84

This corresponds to a TAS of ~484 kt with a wind at 13kt at 72°. The average Mach is at 0.84.

Segment 11 - BW Subset 6

Data Subset 6 includes 13 elements and last about 1min36s. A detailed review of the time interval between the samples shows that 2 of them are 16s long and 6 are 8s long or so. This means that 12 echoes are missing which represents 33% of the total number of potential echoes to be received.

Table 22: Flight characteristics from Excel data for BW subset 5 (to BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-6 Excel	17:59:47.00	18:01:23.20	01:36.20	14.1	528	0.90
BW-6 Excel	Great circle from 1st echo to last echo		01:36.20	13.8	515	0.89

This corresponds to a TAS of ~518 kt (or 505 kt along the direct path) with a wind at 13 at 72°. The average Mach is 0.90 which is unrealistic above the flight envelope limit of 0.87.

Segment 12 gap between BW subset-6 and the Last radar Echo at 18:22:12

Between the last echo of Subset 6 and the last radar echo at 18h22:12 the time interval is close to 21 minutes. The aircraft is flying above the sea in the northwest of the Penang Island en route to VAMPI, MEKAR and 10Nm further.

Table 23: Flight characteristics on the segment of the gap between BW subsets 6 and 18:22:12 (from BW, True height 40500ft)

Subset	Start Time	End time	Delta Time	Distance (Nm)	Average ground Speed (kt)	Mach
BW-6-LSTRP	18:01:23.20	18:22:12.00	20:48.80	175.6	506	0.86

This corresponds to a TAS of ~497 kt with a wind at 12 at 73°. At this flight level, the average Mach is at 0.86 just below the flight envelope limit.

Conclusion

The following conclusions can be drawn from this global analysis:

1. The data is composed of 6 uneven sets separated by large gaps showing the low quality of the radar tracking
2. The time tags are very irregular and do not reflect the antenna rotation (about 4s) with a proper dating of the echoes
3. A lot of echoes have been missed inside each subset
4. The summary of the average ground speed and the average Mach is presented in Table 24.

Table 24: Summary of the speeds within ButterWorth radar coverage at True Heigh 40500ft i.e. FL384

Segment	Ground speed (kt)	Mach	Distance (Nm)	Data availability
1	533	0.90	15.4	Radar data
2	*534*	*0.89*	*15.4*	*gap*
3	540	0.90	0.6	Radar data
4	*532*	*0.89*	*13.1*	*gap*
5	555	0.93	6.2	Radar data
6	497	0.83	6.7	*gap*
7	512	0.86	38.5	Radar data
8	*502*	*0.85*	*9.5*	*gap*
9	565	0.96	3.1	Radar data
10	*494*	*0.84*	*7.7*	*gap*
11	515	0.90	14.1	Radar data
Overall	521	0.88	130.3	

5. Table 24 shows that at FL384 all radar covered segments but one post Mach values well above the flight envelope limit of 0.87. This average across all segments is also above at 0.88.
6. Interestingly, it is when the aircraft is "captured" by the radar that its speeds is unrealistic while in the gaps it appears to fly more reasonably. This leads to question the data time information as the coincidence of the acceleration when "in the available data" is certainly not realistic.

For information Table 25 presents the characteristics of the flight segment after exiting ButterWorth approach radar coverage from 18:01:23 till 18:22:12.

Table 25: Characteristics of the segment from 18:01:23 UTC to 18:22:12 UTC

Segment	Ground speed (kt)	Mach	Distance (Nm)	Data availability
12	*506*	*0.86*	*175.6*	*Gap*

This corresponds to a TAS of ~497 kt with a wind at 12 at 73°. At this flight level, the average Mach is at 0.86 just below the flight envelope limit.

5.2 Geometrical analysis

Considering the origin of the data set which is given to be from the approach radar at ButterWorth, one should ask the question: why the data does not present any cone of silence. In addition, the farthest echo (the last one at 18h01:23 UTC) is located at a slant range of ~77.5 Nm

The radar specifications documentation presents four versions of the NEC radar as described in Figure 4. From the above, one could conclude that the model installed at ButterWorth is the most powerful version with a range capability of ~80Nm at a maximum true height of 45000ft. It is the only version matching the recorded data.

Frequency		2,700 to 2,900 MHz			
Typical instrumented range		80 nmi. / 45,000ft.	80 nmi. / 26,000ft.	60 nmi. / 22,000ft.	60 nmi. / 35,000ft.
Radar Cross Section		2 m^2	15 m^2	15 m^2	2 m^2
Accuracy (range/azimuth)		≦ 150 m (range) ≦ 1.5° (azimuth)	≦ 150 m (range) ≦ 1.5° (azimuth)	≦ 150 m (range) ≦ 1.5° (azimuth)	≦ 150 m (range) ≦ 1.5° (azimuth)
Pulsewidth (Long/Short)		1 μS / 80 μS	1 μS / 80 μS	1 μS / 80 μS	1 μS / 80 μS
Transmitter	**Modules**	90	54	16	24
	Peak Power	50 kW	32 kW	10 kW	16 kW
Antenna	**Gain**	≧ 34.5 dB	≧ 34.0 dB	≧ 34.0 dB	≧ 33.0 dB
	Polarization	Linear / circular	Linear / circular	Linear / circular	Linear / circular
	Rotation rate	15 rpm	15 rpm	15 rpm	15 rpm
	Beamwidth	1.3 deg.	1.3 deg.	1.3 deg.	1.4 deg.
Receiver	**Subclutter visibility**	≧ 35 dB	≧ 35 dB	≧ 33 dB	≧ 35 dB
	Pulse compression ratio	80:1	80:1	80:1	80:1
	Noise figure	≦ 1.6 dB	≦ 4 dB	≦ 4 dB	≦ 1.6 dB
		6-pulse	6-pulse	6-pulse	Capture d'écr

Figure 4: Butterworth approach radar specifications (Source NEC)

A simple geometrical measurement at the closest received echo shows that the elevation was 28° for a true height at 40500ft. Thus, the aircraft stayed most likely within the beam without entering the CoS.

Figure 5 illustrates the geometrical measurements made considering ButterWorth radar sensor as the reference centre.

In this case, the mountains in the northeast are a factor limiting the maximum range detection. Thus the 1st echo at the entry of the radar coverage in the north-east and the last echo in the north-west do not lay on the same orange circle i.e. 42.3Nm and 77.2Nm (~35Nm i.e. ~75% difference). As the difference is influenced by the mountains on the entry side, a comparison is not possible.

These results are summarised in Table 26

Table 26: Distance of min/max echoes for Approach radar at ButterWorth (Aircraft at True height 40500ft)

Approach radar at BW Airport	***Distance (Nm)***	***Difference***	***Relative diff. to shortest***
1st echo in radar coverage	42.3		
Last echo in radar coverage	77.2	n/a	n/a limited by mountains

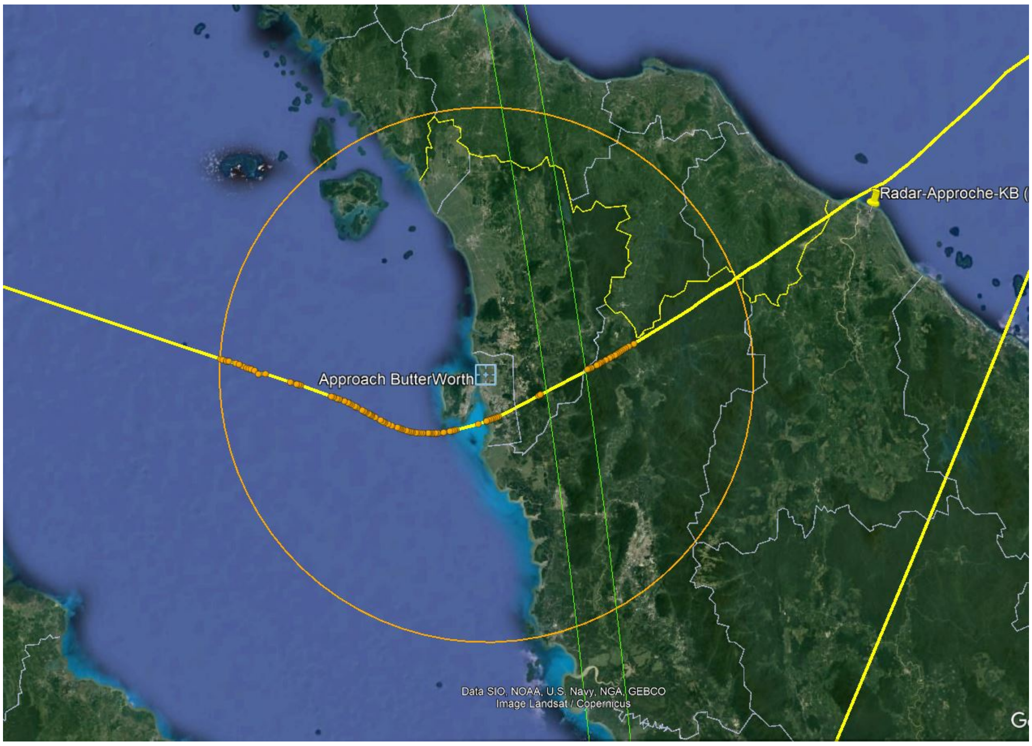

Figure 5: ButterWorth 1st echo is close because of high terrain and last echo is on the Max Orange circle

5.3 Conclusions

As for the previous set of data at KB, the data made available here by the IG presents the characteristics of "track" data in the ASTERIX sense as opposed to "plot" data. Compared with the SELEX radar manufacturer official data posted in the Malaysian report [1], the recorded data shows differences in the time information.

A summary of the evaluation of the computed average Mach in the different segments when the aircraft was inside the ButterWorth radar coverage area is presented Table 27.

Table 27: Summary of the average Mach within ButterWorth radar coverage at True Heigh 40500ft i.e. FL384

Segment	Average Mach	Evaluation
BW-1	0.90	*Overspeed*
BW-2	0.89	*Overspeed*
BW-3	0.90	*Overspeed*
BW-4	0.89	*Overspeed*
BW-5	0.93	*Overspeed*
BW-6	0.83	Acceptable
BW-7	0.86	Acceptable
BW-8	0.85	Acceptable
BW-9	0.96	*Overspeed*
BW-10	0.84	Acceptable
BW-11	0.90	*Overspeed*
Overall	0.88	*Overspeed*

Considering the irregularities in the Mach which are too large to make sense aeronautically, it is logical to consider that the provided data in the Excel file raises an issue. Even though the person in command was eager to get out of the area rapidly, this "roller-coaster" Mach is not realistic and one cannot see how the pilot would succeed maintaining the aircraft at these speeds so long while fighting against the automation and the control column feedback force. This is a very unstable delicate situation.

An average Mach above 0.870 means that the automation will do its most to slow down the aircraft below this limit. Thus, if this was happening, the pilot would have manually flown the segments underlined in Red in the table.

As the geographical locations have been recognised fitting the military data, one should question the times tags assigned to the data in particular.

It is also logical to consider that an unavoidable data selection has been made (may be slightly processed?) by a tracker - or alike - and thus was unavoidably modified during the track records creation at a minimum. In addition, a human intervention had to be necessary to construct a coherent set out of the different tracks because by itself the machine did not recognised the segments as coming back from a unique aircraft. This introduced a subjective aspect in the data. In the Malaysian report, it is visible that the system identified two separate tracks i.e. P1805 (P3415) and then P1812 (P3426). They have been necessarily linked by somebody to make them a track.

Usually, the “raw” data coming out of the sensor head goes through a radar manufacturer proprietary algorithm which may apply some filtering to correct the known sensor imperfections before being properly presented to the decision maker. This is probably why the Excel data are “not clean”.

This means that the time tags of this “track” data cannot be considered as reliable, thus they should not be used for speed or altitude computation without a second source of measurement. In absence of SSR data, ATC experts have confirmed that they avoid doing so when presenting the results on the controller’s screen.

To be convinced about the time tags issue, Table 28 presents the reported time of the first echo considered for each data subset and its corresponding echo given in the Excel file.

Table 28: Comparison of the 1st echo of the different published data subset

Data Subset	1st echo time tag	Source	Category	Comment
P1778	17:30:33.14	Fig 1.1F [1]	Plot (?)	
P1778	17:30:37.02	Fig 1.1G [1]	Track (?)	
KB-1	17:30:34.98	Excel File	???	Misses at least 1 echo
P1793	17:41:00.82	Fig 1.1F [1]	Plot (?)	How could plot data be available later than the track data?
P1793	17:38:56.98	Fig 1.1G [1]	Track (?)	
KB-2	17:38:55.68	Excel File	???	Mismatch with the supposed plot data
P3415	17:47:02	Fig 1.1C [1]	Track (?)	Coasted at 17:48:29
P1805	17:47:01.62	Fig 1.1G [1]	Track (?)	
BW-1	17:46:23.00	Excel file	???	Starts 39s earlier than P1805
P3426	17:51:45	Fig 1.1C [1]	Track (?)	
P1812	17:51:44.38	Fig 1.1G [1]	Track (?)	
BW-3	17:51:23.24	Excel File	???	Starts 22s earlier than P3426

This confirms that three sources of information are available for the time information with obvious incoherence. Thus, time tags should be considered as unreliable as provided.

6 Conclusions

6.1 At FL384, it is unrealistic

Considering that the two sets of radar data origins are the radar sensor at Kota Bharu approach and the one at ButterWorth approach, the analysis above reveals a serious problem as the time tags are concerned. In addition, the data provides the track as non-contiguous segments. This poses the question whether the data is timely reliable or has been improperly time retagged when it was manually selected and reformatted into Asterix format.

This explains why in the official Malaysian report the civil data is said to match the military data geometrically as noted but presents time inconsistencies as underlined in the same report. This poses also the question whether military and civil data does come from the same data fusion source 😊.

Table 29 summarises the finding at true height 40500ft (FL384 at that time) and underlines clearly the following speed paradox: when the aircraft is in the radar coverage it appears to have flown fast and when it was outside the radar coverage it flew slower. This synchronised change of speed with “in the radar beam/out of radar beam” coincidence is unrealistic. The conclusion is that there is a bias in the time stamps of the radar data that provides slow and fast speed inappropriately but surely coming from the time stamping of the radar system. In addition, a speed being at Mach 0.88 in **average** is highly improbable as a pilot planning to fly at least 6 hours longer with the aims to leave no traces would not take the risk to trespass systematically the flight envelope during more than 260 Nm as suggested by Table 29.

Table 29: Summary of average speeds within Kota Bharu radar coverage at True Heigh 40500ft i.e. FL384

Sector	Ground speed (kt)	Mach	Distance (Nm)	Data availability
U-Turn/1st echo	*457*	*0.76*	*45.0*	*Below or equal to 241kt = minimum speed of manoeuvrability*
KB Radar	525	0.88	120.8	Radar Data
Gap KB-BW	*523*	*0.88*	*17.2*	
BW radar	521	0.88	130.3	Radar Data
Exit BW-LSTRP	*506*	*0.86*	*175.6*	

This would mean that the pilot had fought against the aircraft automation during more than 30 minutes. Maintaining the aircraft at this speed so long while fighting against the automation and the strong control column feedback force is not credible.

In addition, there is no rationale to explain why the aircraft would have flown so slow at the minimum speed of manoeuvrability or below (i.e. IAS 241kt) between the Exit point of the U-Turn and the entry into the Kota Bharu radar coverage and then would have speed up above the flight envelope.

As said before this would mean that the piloting was manual placing the aircraft in a very unstable risky situation of overspeed for much too long especially when considering that the aircraft was under depressurisation and thus with the oxygen mask on.

Thus, at this stage of knowledge, a detailed speed estimation of the aircraft from this Excel file data would not be done on solid ground.

Subsequently, there is not enough information so far to sustain that the local speed of the aircraft computed from this data is "proven" and casted in concrete.

The best use of these data is only via their geographical position ignoring the time tags because there is a potential flaw in the time tagging.

Would there be still people believing in the time tagging, then the only acceptable way to do so is to consider the overall values as presented in Table 29 and to reconsider the parameter that was fixed a priori from the beginning: the flight level.

6.2 What about at FL300?

Considering the report from Captain Blelly and JLuc Marchand [2], and its figure 25 reproduced in Figure 6 below, one can see that the maximum true height for the mobile phone to be detected in the south of Penang Island is ~32500ft. This corresponds to a maximum flight level FL310 at that time. Thus, FL384 is an altitude where a mobile phone would not be detected by the ground station.

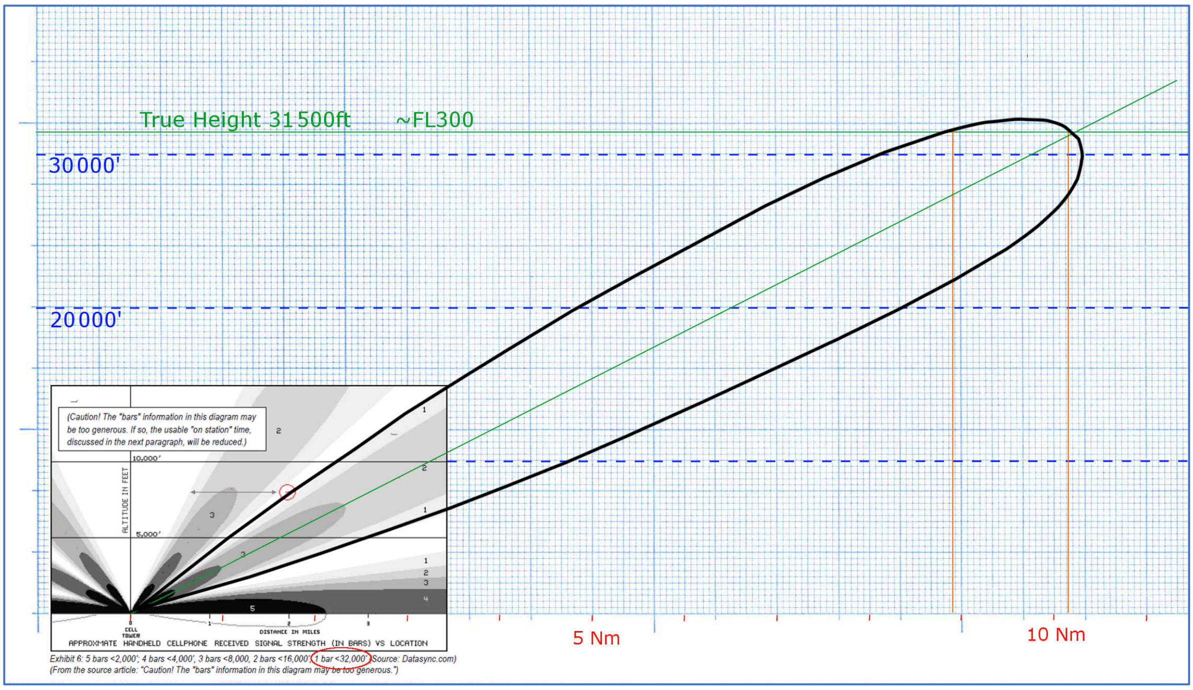

Figure 6: Extrapolation of the Celcom terrestrial antenna secondary lobe power diagram (source Datasync.com)

Thus recomputing Table 29 values for FL300 which corresponds to the true height of 31500ft and which is compatible to a possible detection by the Celcom antenna, one obtains the new values presented in Table 30.

Table 30: Summary of the speeds within Kota Bharu and ButterWorth radars coverage at True Heigh 31500ft i.e. FL300

Sector	Ground speed (kt)	Mach	Distance (Nm)	Data availability / IAS
U-Turn/1st echo	*455*	*0.74*	*44.9*	*IAS 277*
KB Radar Coverage	526	0.86	121.2	Radar Data, IAS 319
Gap KB-BW	*511*	*0.82*	*16.8*	*IAS 312*
BW radar coverage	523	0.84	130.8	Radar Data, IAS 311
Exit BW-LSTRP	*506*	*0.82*	*175.5*	*IAS 304*

One can see that the average Mach of the aircraft stays permanently and comfortably well below the M0.87 upper limit of the flight envelope. This is in accordance to what a pilot would do to fly safely well below the flight envelope limit while matching the ground speed indicated by the radars.

But as for FL384, this does not satisfactorily explain why the aircraft would have flown so slow between the Exit point of the U-Turn and the entry into the Kota Bharu radar coverage at Mach 0.74 and then would accelerate (above the flight envelope at FL384).

As explained above, climbing is not at all a satisfactory explanation for both reasons of an overspeed and a too high altitude for the mobile phone to be detected.

Both scenarios based on the radar time tags are not satisfactory. This calls for a proper, solid way to allow a reasonable computation of the speed.

6.3 How to estimate the speed?

What would be the most reasonable way to estimate the speed between the Exit point of the U-turn and the exit of the radar coverage at 18h22:12? … by using the well-known facts.

Three positions of the aircraft and their respective time tags are well known. Let's use them and follow the airmen's way to compute average speed on these two segments. This is largely sufficient.

The results of this straightforward operational method are presented in Table 31.

Table 31: Average Ground speed estimation from Exit point of the U-Turn at IGARI until the last radar spot

Data set	***Distance (Nm)***	***Time Tag (hr:min:sec)***	***Estimated Average ground Speed (kt)***	***Mach***
Exit Point U-Turn IGARI		17:24:40		
Mobile phone detected	234	17:52:27	506	0.815
10 Nm after MEKAR	252	18:22:12	508	0.815

The respective average speeds across the two segments are very close to each other. Thus, the only sensible, undisputable way to proceed is to consider that the average speed was ~506kt from 17h24:40 until 18:22:12 (don't forget that at the end the aircraft accelerated between MEKAR and the Last Radar spot location which makes the average speed on the segment a little higher).

We do consider that using an average speed is much more realistic and coherent than using "roller-coaster" instantaneous speed values which are anyway irrelevant as we know when the aircraft was at 17:24:40 and at 18h22:12.

Thus, one can consider that this analysis is an "interesting dissertation" concluding that according in the signal processing theory perspective, using these three known points is the most efficient low-pass filter and is much more reliable than any window sliding, ARMA or averaging filter processing as it gives speed estimates for a safe and secure flight.

Thus, the most reasonable speed estimation is based on the airmen's way to estimate average speed "distance/time" with solid data i.e. at the exit point of the U-Turn after IGARI, at the location of the detection of the co-pilot's mobile phone and later at 10 Nm away from MEKAR when the last radar echo was received at 18h22:12. This provides the average ground speed value of 506kt between the U-Turn Exit Point and MEKAR.

7 Data format considerations

Our understanding is that the data was made available to the IG via files containing logs in ASTERIX format.

ASTERIX is an open application/presentation protocol at layers 6 and 7 of the telecommunication network ISO standard. It is a standard way to format surveillance data (initially radar data but today it applies actually to much more types of data) to facilitate the exchange of data between different proprietary surveillance systems. Thus, a necessary conversion has to take place before any exchange in this open format across the Malaysian network between ATS service providers. This conversion ranges from a simple reshuffling of bits up to complex data processing like tracking algorithms for example. Thus, this conversion could potentially modify the original genuine data. The ATS clients usually perform data fusion and provide the best information on the screen of the controller in charge.

Subsequently several issues appear immediately when concerning the MH370:

1- Was the data given to IG in ASTERIX format handled or processed by a kind of RMCDE Front End or equivalent Malaysian Front End?
2- Do the logs contain plots records or tracks records?
3- What is the identifier fields value? These fields include the Sensor identifier or the front-End processor that converted the data i.e. the last one that "manipulated" the data.
4- Are we able to know which processor/server corresponds to the identifier? This info might be classified for obvious security reasons. This could possibly allow to know what proprietary conversion software/system had been used, but with few chances to get a grasp on the proprietary algorithm itself.

Having the data in Asterix format in a set of segments visually gathered means that some gathering of the data and some reformatting took place. How the timing information was handled is unknown.

The only way to get an answer to these questions is to parse the data, extract the identifier in the SIC/SAC fields and ask Malaysian Authorities to which Sensor or Front End it corresponds.

It should be noted that, since no precise knowledge of the altitude has been published so far, this means that the data contains only one source of information at a given time. With two sources it would be possible to calculate the altitude with a good precision. So, each of the data sets comes from one source only.

Another important remark is that in order to create the logs file without possible correlation with any SSR data, someone had to manually select the specific plots or tracks supposedly coming from the MH370 and designate them as such. Doing so means "manipulating" the data may be by a temporal interpolation for example depending on the system architecture and the client requesting the data.

8 References

[1] Safety Investigation Report, The Malaysian ICAO Annex 13 Safety Investigation Team for MH370, 02 July 2018

[2] Analysis of the trajectory of Flight MH370: Technical and Aeronautical analysis from take-off to the end of the flight, Captain Patrick Blelly; Jean-Luc Marchand – 22 March 2023, www.mh370-caption.net