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May, 2016

# Malaysia Airlines Flight 370: Evaluation of Key INMARSAT / ATSB Assumptions

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***MALAYSIA AIRLINES FLIGHT 370  
EVALUATION OF KEY INMARSAT / ATSB ASSUMPTIONS***

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## Introduction

The disappearance of Malaysia Airlines MH370 on March 8, 2014 remains a mystery. It appears that the aircraft crashed somewhere in the Indian Ocean, yet neither the exact location nor the reason for the crash has been determined.

On June 26, 2014, the Australian Transport Safety Bureau (ATSB) released a report describing the methodology that was used by INMARSAT analysts to project the route of MH370 and to define the area off of the western coast of Australia where the aircraft was presumed to be lost.<sup>1</sup> Enormous resources have been devoted, without success, to a thorough search of this area.

The ATSB report provides details regarding the assumptions utilized by the INMARSAT analysts. This report focuses on these assumptions, concludes that one specific assumption is faulty, and suggests that once this assumption is relaxed, the available information can be woven into a coherent explanation of the most likely cause of the crash and prediction of the most probable location of the crash site. This explanation and prediction differ significantly from the explanation and prediction advanced by ATSB based upon the INMARSAT analysis.

## Analysis

The available facts are consistent with the hypothesis that Malaysia Airlines MH370 suffered a catastrophic fire. In July 2011, an EgyptAir Boeing 777-200, nearly identical to MH370, was parked at Cairo airport when an electrical fire erupted in the cockpit near the first officer's oxygen mask supply tubing. The captain ordered the first officer to leave the cockpit immediately and notify the cabin crew. Fed by the crew oxygen system, the fire burned fiercely, forcing a complete evacuation of all passengers. The fire destroyed the cockpit, burning two holes through the skin of the aircraft and causing molten metal to drip into the aircraft's electronics bay despite the captain's efforts to extinguish the fire using the cockpit fire extinguisher (Figure 1 and Figure 2). The resulting investigation determined that 380 Boeing 777's were delivered to various airlines without protective sleeves for wires to the first officer's oxygen module.<sup>2</sup> Boeing conducted an extensive test program to determine if the oxygen system hoses were electrically conductive and if they could have ignited in the presence of an electrical fault involving these components. The test results indicated that some hoses used in the crew oxygen system were electrically conductive and if a sufficient electrical current is flowing through them the hoses may heat to the point of ignition. On April 19, 2012, Boeing issued revised service bulletin 777-35A0027 to replace the hoses with nonconductive hoses. Effective August 16, 2012, the U.S. Federal Aviation Administration (FAA) issued air worthiness directive AD 2012-13-05 to replace existing electrically conductive low pressure oxygen hoses with electrically nonconductive hoses on all Boeing 777-200 aircraft. All United States-based airlines were required to comply with the directive by February 16, 2014. While Malaysia Airlines is not governed by the FAA, Malaysia's Ministry of Transport issued a report regarding MH370 in March 2015 which stated:

Maintenance and Inspection records provided by MAS indicate that at the time the aircraft

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<sup>1</sup> Australian Transport Safety Bureau, "MH370: Definition of Underwater Search Areas, ATSB Transport Safety Report AE-2014-054," [http://www.atsb.gov.au/media/5243942/AE-2014-054\\_MH370\\_SearchAreasReport.pdf](http://www.atsb.gov.au/media/5243942/AE-2014-054_MH370_SearchAreasReport.pdf).

<sup>2</sup> Aircraft Accident Investigation Central Directorate, "Final report concerning EgyptAir Boeing 777-200 aircraft cockpit fire at Cairo Airport on 29th July 2011 registration SU-GBP flight no. MS 667 Cairo/Jeddah," (Cairo, Egypt: Egyptian Ministry of Civil Aviation, 2012).

9M-MRO went missing, the aircraft and engines were fully compliant with all applicable Airworthiness Directives (AD). The most recent AD, which was accomplished on 17 Jan 2014, was FAA AD 2012-13-05 (Replacement of Low Pressure Oxygen hose).

If the hose was replaced, any likelihood of an electrical fire would have been greatly diminished. However, a report by Mike McKay, a worker on the Songa Mercur oil drilling platform in the South China Sea, suggests that MH370 was victimized by a fire with characteristics that are consistent with the type of fire that would result if the hose had not been replaced or was incorrectly replaced. McKay observed an aircraft at high altitude burning in one piece about 50-70 km from his location, shortly after MH370's first officer radioed his last message, "good night, Malaysian three-seven-zero." Consistent with McKay's report, MH370's transponder noted a course change prior to loss of contact that would have taken MH370 to a waypoint identified as BIBAN, within visual range of the oil rig. ABC's Bob Woodruff obtained McKay's letter and the image of this letter was posted online.<sup>3</sup>



Figure 1. Electrical fire destroyed cockpit of EgyptAir 667

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<sup>3</sup> Abby Ohlheiser, "Oil rig worker thinks he saw Malaysia Air flight 370 go down in flames "  
<http://www.thewire.com/global/2014/03/oil-rig-worker-says-he-saw-malaysia-air-flight-370-go-down/359093/>.



Figure 2. Fire burned through the skin of EgyptAir 667

McKay stated that the aircraft was on a compass heading of 265° to 275°, in other words, due west of McKay's location. This is consistent with MH370's initial left turn, which placed the aircraft on a heading due west, back toward the coast. McKay stated that after 10-15 seconds, the flames went out, with the aircraft at high altitude. Whether or not Malaysia Airlines replaced the cockpit oxygen hose with a nonconductive hose, McKay's report suggests that MH370 was victimized by a brief, intense fire that breached the hull at altitude, caused cabin depressurization, and was then rapidly extinguished by depressurization. While the Ministry of Transport report suggests that the hose was not the problem, it is noteworthy that a brief, intense fire that breaches the hull and causes depressurization is the type of fire that would be produced if the oxygen hose on MH370 was not properly replaced.

The fact that the aircraft flew until fuel exhaustion is a strong indication that the crew was disabled, yet the flight management system, engines and fuel systems remained operational throughout the flight. These clues are also consistent with a brief, intense fire that breaches the hull, causes depressurization, disables the crew, and is extinguished before the fire disables the flight management system, engines and fuel systems.

While the images of the EgyptAir 667 cockpit suggest major damage, the aircraft was on the ground when the cockpit oxygen hose ignited. The fire continued to be fed by air flowing freely into the cockpit. The fire was not extinguished through depressurization and was only extinguished with great difficulty.

MH370's seemingly odd behavior is consistent with the hypothesis that the aircraft was victimized by the same type of cockpit fire suffered by EgyptAir MS667. At 1:19 am, the first officer responds, "good night, Malaysian three-seven-zero" to Malaysian air traffic control, but he has no reason to indicate distress. However, this transmission may have accompanied by an electrical short circuit that ignited a fire in the first officer's oxygen hose tubing. The first officer is forced to leave his seat. At 1:21 am, the pilot presses two buttons to activate the main circuit breakers and shut down all electrical equipment, seeking to kill the source of ignition and isolate the short circuit but inadvertently disabling the radios and transponders. However, an oxygen-fed fire from the copilot's oxygen hose would produce an intense fire that would be extremely difficult if not impossible to extinguish with the onboard equipment. The pilots battled to extinguish the fire while attempting to fly the aircraft. The captain diverted the aircraft, commanding the autopilot to turn left, following a direct route to the nearest airport, at Kota Bharu on the east coast of Malaysia, consistent with a report that fishermen from Kota

Bharu observed the aircraft flying unusually low, heading west.<sup>4</sup> The airport's 7874 foot runway would have been sufficient to accommodate MH370.

McKay's observation of the aircraft on fire at a distance of 50-70 km suggests that the fire was fierce, requiring the crew's full attention. The first priority would have been to fly the aircraft and fight the fire, not to communicate with air traffic controllers. If the crew oxygen system was disabled or destroyed as hypothesized, it would be unavailable in an emergency. If the fire burned through the skin of the aircraft at high altitude, rapid depressurization would result, extinguishing the fire—but causing the crew to lose consciousness within minutes, consistent with the observation that if the aircraft flew until its fuel was exhausted the crew was most likely incapacitated. The passengers would also be incapacitated.

Significantly, the Boeing 777 has a 'fly by wire' system that uses computers to translate the pilots' control inputs to the control surfaces on the wings and tail of the aircraft. For safety reasons, the flight control system is powered by redundant sources and does not shut down even if the pilot shuts down all other electrical equipment. Another design feature of the 777 is that the aircraft fly-by-wire system provides stability augmentation and compensates for any change in the aircraft's center of gravity as fuel is consumed. This provides longitudinal stability to the aircraft and maintains the trim condition throughout most of the flight. The flight control system automatically compensates for asymmetric forces and can handle an engine failure in one engine. Bill Palmer, a B-777 type rated pilot for a major US airline and author of *Understanding Air France 447*, has explained that a Boeing 777-200 could theoretically remain airborne without input from the crew or autopilot and could fly unattended for over seven hours until fuel exhaustion.<sup>5</sup> The aircraft would remain aloft but would not be expected to fly a perfectly straight course.

The last recorded position of the aircraft, tracked by military radar at 2:15 am, placed the aircraft on a course heading toward the Maldives. Later that morning, several residents of Kudahuvadho in Dhaal atoll in the Maldives reportedly saw a low-flying white aircraft with red stripes flying north to south-east, towards Addu at the southern tip of the Maldives, around 6:15 am local time on the morning of March 8, flying so low that the aircraft doors were clearly visible.<sup>6</sup> No regular flights fly over the atoll at that hour. Dhaal atoll is 1900 miles due west of Malaysia, on the last known flight path of MH370. The markings on the unknown aircraft are consistent with the markings on MH370. Malaysia's National Defence Force stated that MH370 was not observed on radar—but it would not be observable if it was flying very low. The odd direction of the south-east flight path might be explained if the autopilot was disengaged, the aircraft had been buffeted by strong Indian Ocean winds over the atoll, and the aircraft had recovered from this buffeting on a south-easterly heading. Alternatively, if the aircraft was low on fuel, power to the left engine may have been reduced, causing a slow turn to the left.

6:15 am local time is 9:15 am Malaysian time—8 hours and 34 minutes after takeoff, in other words, very near fuel exhaustion. If the report is accurate, MH 370 most likely crashed into the Indian Ocean southeast of Dhaal atoll in the Maldives (Figure 3). That is where the search should be concentrated.

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<sup>4</sup> Bob Woodruff, "Lead in MH370 hunt?," ABC News, <http://abcnews.go.com/International/fishermen-plane-sighting-tip-false-lead-mh370-hunt/story?id=22954793>.

<sup>5</sup> Bill Palmer, "Pilot: Was that Boeing 777 diverted deliberately? Not necessarily," CNN, <http://www.cnn.com/2014/03/16/opinion/palmer-malaysia-flight-370/>.

<sup>6</sup> Farah Ahmed and Ahmed Naif, "Maldives island residents report sighting of 'low flying jet'," Haveeru Online, <http://www.haveeru.com.mv/news/54062>.

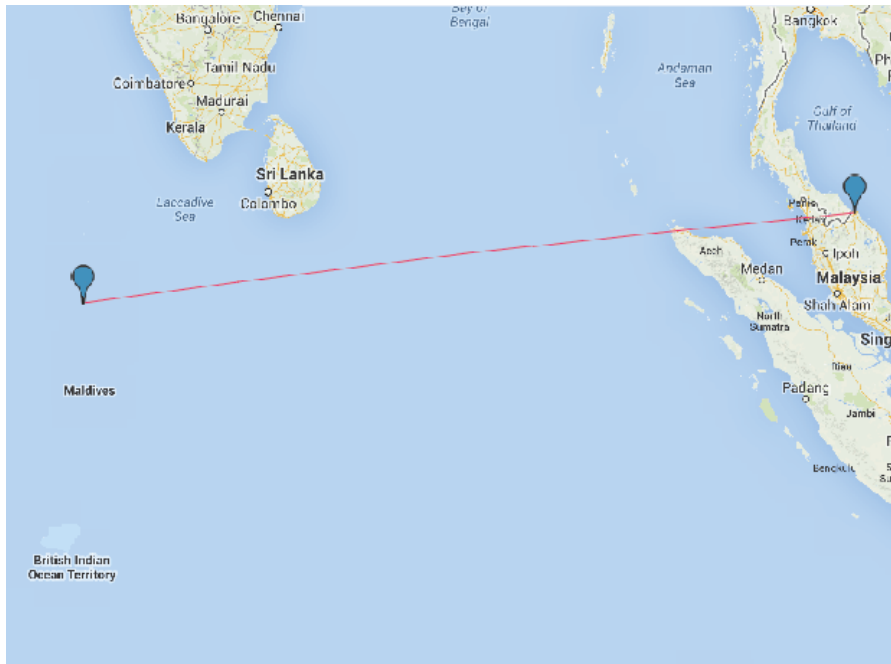


Figure 3. Projected path of Malaysia Airlines 370 from Kota Bharu Malaysia to Dhaal Atoll in the Maldives

The existing search has been focused off the western coast of Australia based on an analysis of INMARSAT satellite 'ping' information. However, this analysis depends on a particular interpretation of the signals between the satellite and MH370 that may not be correct.

Chris McLaughlin, INMARSAT's spokesman, stated that the distance between the INMARSAT satellite and MH370 was calculated based upon the return time of MH370's ping to the INMARSAT satellite after subtracting an estimate of the signal processing delay. The "increasing number of milliseconds" between these adjusted ping delays (labeled "burst timing offset" or BTO) led analysts to believe that the aircraft was "moving away" from the satellite. This information was plotted on a map, producing the curved arc seen on various graphics, leading the search team to focus on the area off the western coast of Australia.

The INMARSAT analysts asserted that they were able to accurately estimate and account for every component of the ping delay that might have confounded their calculations. The primary conclusion of the analysis presented here is that the INMARSAT analysts were not able to accurately estimate and account for every component of the ping delay that might have confounded their calculations.

The total variability in ping delay is large. INMARSAT's own manual states: "The absolute latency of the INMARSAT network is therefore not only a significant factor to be taken into account in itself but its variability, known as jitter, also becomes a significant factor that needs to be considered."<sup>7</sup> Data from a presentation by Matt Esposito at the 9th Annual Satcom Direct Conference indicate that the total INMARSAT satellite signal latency varies from 1200 to 3500 milliseconds.<sup>8</sup> In comparison, if MH370

<sup>7</sup> INMARSAT, "FleetBroadband best practices manual," [http://www.inmarsat.com/wp-content/uploads/2013/10/Inmarsat\\_FleetBroadband\\_Best\\_Practices\\_Manual.pdf](http://www.inmarsat.com/wp-content/uploads/2013/10/Inmarsat_FleetBroadband_Best_Practices_Manual.pdf).

<sup>8</sup> Matt Esposito, "9th Annual Satcom Direct Conference," <http://www.satcomdirect.com/Connect/Presentations2013/SatcomUniversity/Satcom%20University.pdf>.



traveled 1900 miles toward a point under the INMARSAT satellite, the slant distance to the satellite would decrease by 81 miles. Radio waves travelling at the speed of light would have less distance to cover and would arrive more quickly. However, an 81 mile reduction in distance would reduce the ping latency by only 0.9 milliseconds—a tiny fraction of the total 1200 to 3500 millisecond ping latency. Therefore, any calculation that employs differences in ping latency to estimate the location and direction of travel of MH370 depends on extremely precise calculations to subtract all of the noise in the 1200 to 3500 millisecond ping delay. A failure to properly account for even a single millisecond of this noise would cause a 1900 mile error in the calculation of the arcs along the surface of the earth describing MH370's possible location. Significantly, the procedures used by the INMARSAT analysts are inherently unable to account for a specific source of noise that would be expected to occur after MH370 departed from Kuala Lumpur, and would be expected to occur on flights traveling from Kota Bharu toward the Maldives but not on flights traveling south toward the western coast of Australia. The possibility of this specific source of noise was overlooked by the INMARSAT analysts as well as the independent analysis led by Duncan Steel.

The failure to properly account for this noise means that it contaminated the calculation of the satellite-to-aircraft propagation delay. This means that the INMARSAT data (but not INMARSAT's interpretation of the data) are consistent with the possibility that MH370 traveled west, toward the Maldives, rather than south, toward the western coast of Australia.

The INMARSAT L-band downlink signal is most strongly attenuated 'under' the satellite, i.e., southwest of Dhaal atoll (the gain at the sub-satellite point is -2.5 dB relative to beam peak).<sup>9</sup> If MH370 traveled west from Malaysia toward the Maldives, then it traveled from an area where the L-band downlink signal strength was strong to an area where signal strength was weaker. The aircraft receiver would experience more interference because incoming signals would increasingly be reflected directly off of the sea as the aircraft approached Dhaal atoll. If MH370 traveled west from Malaysia toward the Maldives, then it traveled from an area where signal interference was relatively weak to an area (toward the subsatellite point) where signal interference was stronger.

Signal attenuation and increased interference would increase the probability of dropped data packets. In the absence of knowledge about why a data packet was dropped (network congestion or corruption), the standard network protocol is designed in a way that minimizes the possibility that the network would collapse due to congestion. The protocol forces the equipment that is used for digital signal processing to reduce the data packet transmission rate. This protective measure increases ping response time, even though the packet drops (in this case) do not signal congestion in the network.<sup>10</sup> Neither the INMARSAT analysis nor the independent analysis led by Duncan Steel accounted for this effect.

The potential magnitude of the effect is significant. Assuming, for example, a bit error rate of  $1 \times 10^{-5}$ , a decrease in signal gain of 0.5 dB involving TCP-governed satellite communications would increase the bit error rate 10-fold and double the total satellite-to-aircraft signal delay.<sup>11</sup> A decrease in signal gain of 2.5 dB relative to beam peak would have even larger effects. These effects were ignored by the INMARSAT analysts.

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<sup>9</sup> Attachment A, "INMARSAT-3 F3 (178.1° E.L.) technical description (INMARSAT-C Service)," (undated), 7.

<sup>10</sup> O3b Networks, "What is Network Latency and Why Does It Matter?," [http://www.o3bnetworks.com/media/40980/white%20paper\\_latency%20matters.pdf](http://www.o3bnetworks.com/media/40980/white%20paper_latency%20matters.pdf).

<sup>11</sup> See John Muhonen and Robert C. Durst, "Performance of transport protocols over satellite communication links" (paper presented at the Military Communications Conference, 1998, Boston, MA, 1998), 266-267.

To summarize, signal attenuation and interference after MH370 departed from Kuala Lumpur would have increased if MH370 traveled west toward the Maldives, increasing the level of noise in the ping delay. This noise was not properly subtracted in the INMARSAT analysis. It contaminated the INMARSAT calculations. This contamination could have easily misled the INMARSAT analysts to conclude that the aircraft was traveling away from the INMARSAT satellite when the aircraft may, instead, have been traveling west, to a position 'under' the INMARSAT satellite in the vicinity of Dhaal atoll, rather than a point off of the western coast of Australia.

While INMARSAT sought to remove any errors introduced by digital signal processing, the procedure for removing this error involved calculating the delay introduced by digital signal processing prior to takeoff, then subtracting this component throughout the period after takeoff. The formula and procedures used by INMARSAT are described in Appendix G of the Australian Transport Safety Bureau report titled, "MH370: Definition of Underwater Search Areas, ATSB Transport Safety Report AE-2014-054".<sup>12</sup> Page 54 of the report supplies the formula for deriving the distance from the INMARSAT satellite to MH370:

$$Range_{(satellite\ to\ aircraft)} = c.(BTO - bias)/2 - Range_{(satellite\ to\ Perth\ LES)}$$

INMARSAT described the "bias" as "a bias component caused by fixed delays in the system", in other words, the assumption employed by INMARSAT is that the delay in signal processing is constant. ATSB assumed that the signal processing delays are "fixed", but they are not fixed. The last paragraph on page 54 states that 17 measurements were taken in the 30 minutes prior to departure from Kuala Lumpur "to estimate the fixed timing bias". ATSB assumed that the signal processing delay was "fixed", calculated a value based on the average of 17 measurements taken prior to departure, and inserted this fixed value into the formula for deriving the distance from the INMARSAT satellite to MH370. This procedure was performed on data received from MH370 throughout the flight, disregarding the possibility that the "bias" value would likely increase if MH370 traveled west toward the subsatellite point.

This procedure is inherently unable to account for any increase in signal processing delay introduced after takeoff. Failure to account for this increase means that existing calculations of the satellite-to-aircraft propagation delay at any point after takeoff were a mixture of true propagation delay plus the unmeasured increase in signal processing delay due to signal attenuation and increased interference after MH370 departed from Kuala Lumpur. The implication is that existing calculations predicting that MH370 traveled south toward the western coast of Australia are likely to be incorrect. While the INMARSAT analysts sought to validate their procedure using data from other Malaysia Airlines flights, they were primarily concerned with the question of whether MH370 flew north toward China or south toward Australia. There is no indication that this type of test was performed with aircraft flying west along a path from Kota Bharu to the Maldives.

The data in Table 1 (below) were constructed to illustrate how it would be possible for INMARSAT's calculation of the satellite-to-aircraft propagation delay to increase if, in fact, the satellite-to-aircraft propagation delay declined, consistent with the hypothesis that MH370 traveled toward the Maldives. The data illustrate how decreases in satellite-to-aircraft propagation delays (column a) could be masked by increases in signal processing delays (column b) if INMARSAT incorrectly assumed fixed signal processing delays or "fixed timing bias" (column c). Subtracting the "fixed timing bias" (250 ms) from the

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<sup>12</sup> See Appendix G of Australian Transport Safety Bureau, "MH370: Definition of Underwater Search Areas, ATSB Transport Safety Report AE-2014-054".

total ping delay (a + b) replicates the procedure that INMARSAT used to calculate the satellite-to-aircraft propagation delay (column d).

Table 1. Illustrative data assuming aircraft traveled toward INMARSAT satellite.

<b>timestamp</b>	<b>total delay (a + b)</b>	<b>satellite to aircraft propagation delay (a)</b>	<b>signal processing delay (b)</b>	<b>INMARSAT "fixed timing bias" (c)</b>	<b>INMARSAT calculation of satellite to aircraft propagation delay (d)</b>
1:11 am	750.0 ms	500.0 ms	250.0 ms	250 ms	500.0 ms
2:11 am	750.1 ms	499.9 ms	250.2 ms	250 ms	500.1 ms
3:11 am	750.2 ms	499.8 ms	250.4 ms	250 ms	500.2 ms
4:11 am	750.3 ms	499.7 ms	250.6 ms	250 ms	500.3 ms
5:11 am	750.4 ms	499.6 ms	250.8 ms	250 ms	500.4 ms
6:11 am	750.5 ms	499.5 ms	251.0 ms	250 ms	500.5 ms
7:11 am	750.6 ms	499.4 ms	251.2 ms	250 ms	500.6 ms
8:11 am	750.7 ms	499.3 ms	251.4 ms	250 ms	500.7 ms

Notes: ms = milliseconds. Esposito's data suggest that the latencies given in the INMARSAT manual are substantially underestimated.

The data indicate that total ping delay is comprised of components including the true satellite-to-aircraft propagation delay (column a) and the true signal processing delay (column b). INMARSAT assumed a fixed signal processing delay (a "fixed timing bias"). This assumption did not account for any increase in this delay after MH370 departed from Kuala Lumpur. INMARSAT subtracted this "fixed timing bias" from the total ping delay to derive an estimate of the satellite-to-aircraft propagation delay. This procedure fails to account for increases in signal processing delays that would be expected to occur if MH370 traveled west to a position under the INMARSAT-3 F1 satellite, where the satellite signal was degraded. This potentially introduced errors in the method of calculating the distance from the satellite to MH370 at every point after takeoff. These errors would be expected to accumulate as MH370 traveled closer to the subsatellite point. The hypothetical data are consistent with the aircraft flying toward the satellite on a western path, despite INMARSAT's calculations suggesting a path away from the subsatellite point.

The magnitude of any change in the satellite-to-aircraft propagation delay as a result of the aircraft traveling toward the satellite may be estimated using a few simple assumptions. If MH370 traveled 1900 miles from Malaysia to Dhaal atoll, and if the INMARSAT-3 F1 satellite is located in a geosynchronous orbit 35,786 km above a point southwest of Dhaal atoll, the direct (slant) distance between the aircraft and the satellite decreased by approximately 81 miles as the aircraft traveled to a position that was 'under' the satellite's orbital position.<sup>13</sup> The roundtrip satellite signal propagation delay would shorten by 0.9 milliseconds.<sup>14</sup> However, an increase in the signal processing delay in excess of 0.9 milliseconds would hide this effect and possibly mislead the INMARSAT analysts to conclude that the aircraft traveled away from the satellite.

<sup>13</sup> The slant distance is the hypotenuse of a right triangle with a leg of 35,786 km and a leg of 1900 miles. The difference between the length of the hypotenuse and the leg of 35,786 km equals 81 miles.

<sup>14</sup> Radio waves travelling at the speed of light cover the 81 mile roundtrip distance in 0.9 milliseconds.

In addition to the total ping delay, INMARSAT also used differences between the expected and measured frequencies of the radio signals received from MH370 to support the conclusion that the aircraft flew southward on a path that ended off the west coast of Australia. The Doppler effect predicts that the frequency of radio signals would increase whenever the aircraft flew toward the INMARSAT-3 F1 satellite. The Doppler effect predicts that the frequency of radio signals would decrease whenever the aircraft flew away from the satellite.

The electronic equipment onboard MH370 automatically adjusted the frequency of the aircraft's transmissions to compensate for the aircraft's speed and heading relative to the satellite, eliminating any Doppler shift associated with the aircraft's movement. However, the INMARSAT-3 F1 satellite is an old satellite. It does not maintain a strict geosynchronous orbit as designed but instead wobbles from north to south and back again on a known path and schedule. Therefore, analysts were able to determine exactly when the satellite was traveling north along this path and when the satellite was traveling south. INMARSAT matched this information against Doppler information regarding changes in ping frequency and concluded that MH370 flew southward. During time periods when the satellite traveled southward, INMARSAT concluded that the changes in the ping frequency indicated that the satellite was getting closer to MH370, indicating that the aircraft was on a southern rather than a northern flight path. However, increases in ping frequency are exactly what would be expected if MH370 had traveled west toward the Maldives, toward the subsatellite point, and closer to the INMARSAT satellite.

The larger problem is that the entire INMARSAT analysis is dependent on the assumption that the errors introduced by signal processing delays were completely eliminated by the procedure used to calculate these delays based on information available prior to MH370's departure from Kuala Lumpur. This assumption is invalid. Signal attenuation and interference after MH370 departed from Kuala Lumpur would have increased if MH370 traveled west toward the Maldives, increasing the signal processing delay. This increase was not subtracted from the calculation of the satellite-to-aircraft propagation delay, causing miscalculation of the satellite-to-aircraft propagation delay and miscalculation of the distance from the INMARSAT-3 F1 satellite to MH370 throughout the flight after departure from Kuala Lumpur. Therefore, the ping data (but not INMARSAT's interpretation of the data) are consistent with the hypothesis that MH370 traveled west--toward the Maldives.

A final clue is an acoustic signal detected by two sets of underwater listening devices located off the west coast of Australia at 1:34:48 am UTC on March 8, 20 minutes after the Dhaal atoll aircraft sighting.<sup>15</sup> In September 2014, additional acoustic data were recovered from a third set of underwater listening devices located at Scott Reef, off northwestern Australia. The data contain a signal at 01:32:49 UTC on March 8 that corresponds to the signal recovered from the two sets of devices located off the west coast of Australia. The additional data recovered in September 2014 permitted researchers to triangulate and refine the previous estimate of the geographic location of the acoustic signal. The time, nature and direction of the signal, and the new estimate of the sound's geographic location (in the vicinity of Dhaal atoll in the Maldives), are consistent with the hypothesis that MH370 crashed south of the Maldives, but are not consistent with the hypothesis that MH370 traveled toward the west coast of

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<sup>15</sup> News Corp Australia Network, "Undersea audio recording could hold MH370 clue, say Curtin University researchers in Perth," <http://www.news.com.au/national/undersea-audio-recording-could-hold-mh370-clue-say-curtin-university-researchers-in-perth/story-fncynjr2-1226942565742>.

Australia. The new estimate places the source of the sound east of Carlsberg Ridge, remarkably close to the sighting of the unidentified aircraft over Dhaal atoll in the Maldives (Figure 4 and Figure 5).

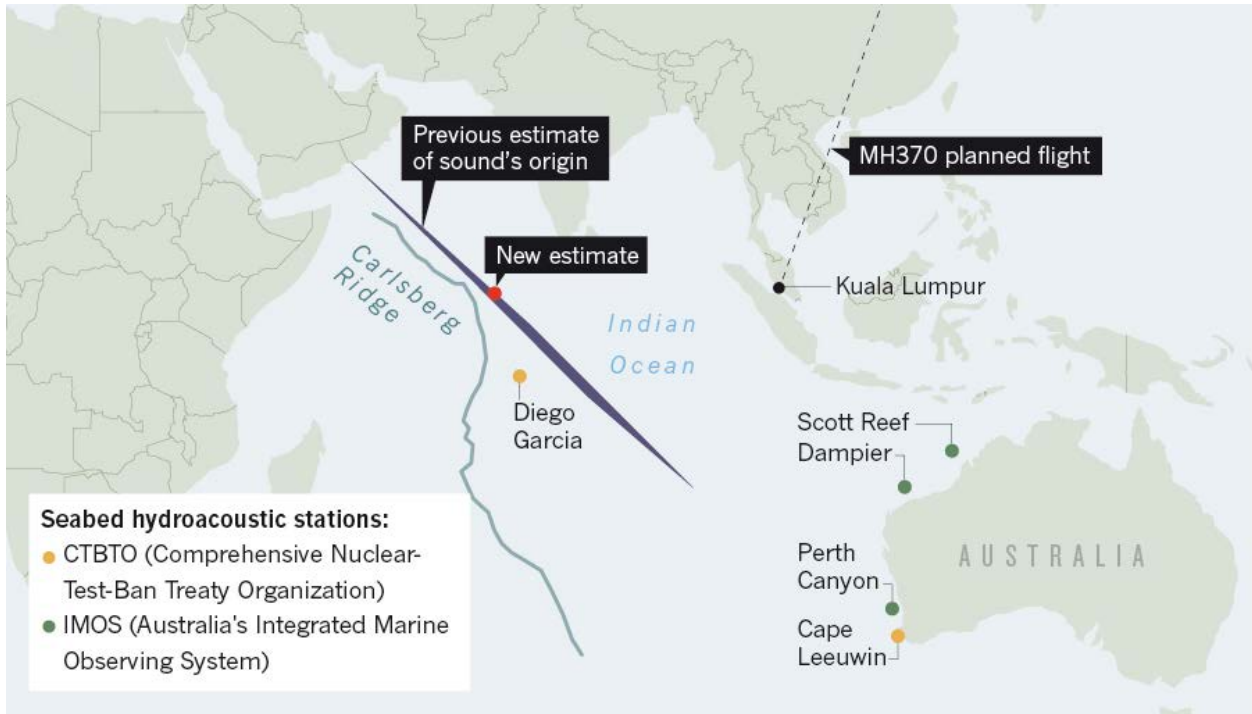


Figure 4. Estimated geographic location of acoustic signal lies east of Carlsberg Ridge near Maldives



Figure 5. Dhaal atoll in the Maldives lies east of Carlsberg Ridge (see red line)

The hypothesized scenario assembles the known facts and an array of seemingly odd information into a coherent explanation of those facts (Table 2).

Table 2. Comparison of Maldives and Australian Transport Safety Bureau theories.

	Maldives Theory	ATSB Theory
Assumes "fixed timing bias" (constant signal processing delay)	No	Yes
Accounts for signal attenuation and increased signal interference if flying west	Yes	No
Explains loss of radio contact	Yes	No
Explains loss of transponder signal	Yes	No
Explains lack of distress call	Yes	No
Explains left turn toward Kota Bharu airport	Yes	No
Explains McKay's sighting of aircraft in flames flying west toward Kota Bharu	Yes	No
Explains flight of aircraft until fuel exhaustion	Yes	No
Explains sighting by Kota Bharu fisherman of low-flying aircraft	Yes	No
Explains last recorded position of MH370 by military radar at 2:15 am	Yes	No
Explains sighting of aircraft with similar markings over the Maldives	Yes	No
Explains acoustic signal detected by three sets of underwater listening devices	Yes	No
Explains failure to locate debris off west coast of Australia	Yes	No
Explains increase in ping frequency (Doppler effect)	Yes	Yes
Is consistent with INMARSAT data	Yes	Yes
Is consistent with INMARSAT's interpretation of data	No	Yes
Implies pilot or copilot plot to kill crew and all aboard	No	Yes

To summarize:

- There is agreement that the aircraft apparently flew until fuel exhaustion; this is a very strong indication that the crew was incapacitated. The most likely scenario is that the crew was incapacitated shortly after contact was lost. If the crew was incapacitated later, the crew would have had an opportunity to issue a distress call.
- If MH370 suffered the same type of cockpit fire suffered by EgyptAir MS667, it is likely that the crew would not have been able to use their oxygen masks and would have been quickly incapacitated, but prior to this would have sought to kill the source of ignition by shutting down all electrical equipment--inadvertently disabling the transponders and radio--and would have diverted the aircraft to the nearest airport at Kota Bharu. This matches what is known about MH370's seemingly odd behavior. It is difficult to imagine another scenario that fits the known facts and would be consistent with rational pilot behavior.
- McKay's observation of an aircraft on fire at high altitude matches this explanation and is otherwise inexplicable. McKay's observation that the fire went out after 10-15 seconds is consistent with the hypothesis that the fire burned through the skin of the aircraft and rapid depressurization occurred. This would have extinguished the fire but would also have caused the crew to lose consciousness within minutes.
- At 2:15 am, military radar tracked the aircraft heading due west, toward the Maldives. This is approximately one hour after radio contact with MH370 was lost. However, if the crew was incapacitated within the first few minutes of a cockpit fire, then the aircraft flew unattended

from that point forward. The fact that the aircraft flew in a westerly direction for at least one hour after the crew was presumably incapacitated indicates that the aircraft was on a western course and probably continued flying west, not south. In contrast, the Australian Transport Safety Bureau crash investigation team is operating under the assumption that the aircraft was abruptly detoured south approximately one hour after contact was lost. This would necessarily require a conscious, deliberate action by the pilots, but is inconsistent with the premise that incapacitation probably occurred within the first few minutes of the loss of radio contact—well before military radar tracked the aircraft heading due west at 2:15 am.

- The observation of an aircraft matching the description of MH370 by residents of Dhaal atoll matches this hypothesis and is otherwise inexplicable. The aircraft was observed flying very low. Low-flying aircraft are not visible on radar. Furthermore, much of the area along the hypothesized route of the aircraft is not covered by radar because it is not a corridor that is used by commercial aircraft.
- Palmer, an expert commercial pilot and an expert regarding the Boeing 777, indicated that the aircraft is capable of flying for seven hours unattended without input from the crew or the autopilot. This is possible because the aircraft is designed, for safety reasons, to be extremely stable and the flight control system is designed to maintain stability automatically.
- The acoustic signal detected by three sets of underwater listening devices located off of the western and northern coast of Australia matches the hypothesis that MH370 crashed near Dhaal atoll, but is inconsistent with the hypothesis that the aircraft crashed off the western coast of Australia. Researchers used the information from the three sets of devices to triangulate the geographic location of the source of the signal and eliminated the possibility that the source was located off of the coast of western Australia. Instead, the researchers believe that the source was located "south of the tip of India"—in other words, near the Maldives.<sup>16</sup>
- The theory that MH370 crashed off the coast of western Australia rests entirely on a single premise: that the INMARSAT analysts correctly accounted for signal processing delays that would normally contribute to the total ping delay of any signal received from MH370. However, as explained above, the procedure used by the INMARSAT analysts is unable to account for the increase in signal processing delay that would be expected if indeed MH370 traveled west toward the Maldives and toward a position 'under' the INMARSAT-3 F1 satellite. The INMARSAT analysts measured the signal processing delay prior to MH370's departure from Kuala Lumpur; this procedure is inherently unable to account for any increase in the signal processing delay after takeoff.

## Conclusion

The analysis presented in this report suggests a need to re-examine INMARSAT's assumption that the signal processing delay did not increase after MH370's departure from Kuala Lumpur, and to consider the possibility that the INMARSAT analysis is based on a faulty assumption.

The INMARSAT analysis implies the conclusion that the pilots commandeered the aircraft for criminal purposes. However, Captain Zaharie Shah was an avid pilot and a grandfather, while his co-pilot, Fariq

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<sup>16</sup> Ibid.

Hamid, was engaged to be married and was planning his wedding, making the pilots unlikely suspects. Instead, an onboard fire remains the most likely explanation, one that fits the known facts. The failure to locate debris from the missing aircraft off the coast of Australia, despite a massive search operation, suggests that the search may be focused in the wrong area.

The current analysis suggests that search efforts should be redirected to the area southeast of Dhaal atoll in the Maldives. The aircraft was sighted 8 hours and 34 minutes after takeoff. Thus, it was very near fuel exhaustion and could not have traveled much further. If so, the search area would not be large. The towed underwater sonar device should be used to sweep this area in an effort to locate debris that presumably sank to the ocean floor. While some debris may have remained afloat and may eventually wash ashore on the east coast of Africa, the aircraft is a metal structure and, therefore, most of it would have sunk to the bottom of the ocean in the vicinity of the crash location, just as much of the debris from Air France 447 and the debris from TWA 800 was eventually located on the ocean floor.

Alec Duncan, at Curtin University's Centre for Marine Science and Technology, stated that "if the sound [detected by two sets of underwater listening devices located off the west coast of Australia 20 minutes after the Dhaal atoll aircraft sighting on March 8] was generated by the implosion of some part of the aircraft as it sank ... at a depth of about 1000 meters, then the resulting sound would propagate effectively in the deep sound channel and could conceivably be detected at ranges of thousands of kilometers". This suggests that the search for MH370 should be concentrated in water that is a minimum of 1000 meters in depth. In sum, the priority search area should be water that is a minimum of 1000 meters in depth southeast of Dhaal atoll in the Maldives (Figure 6).

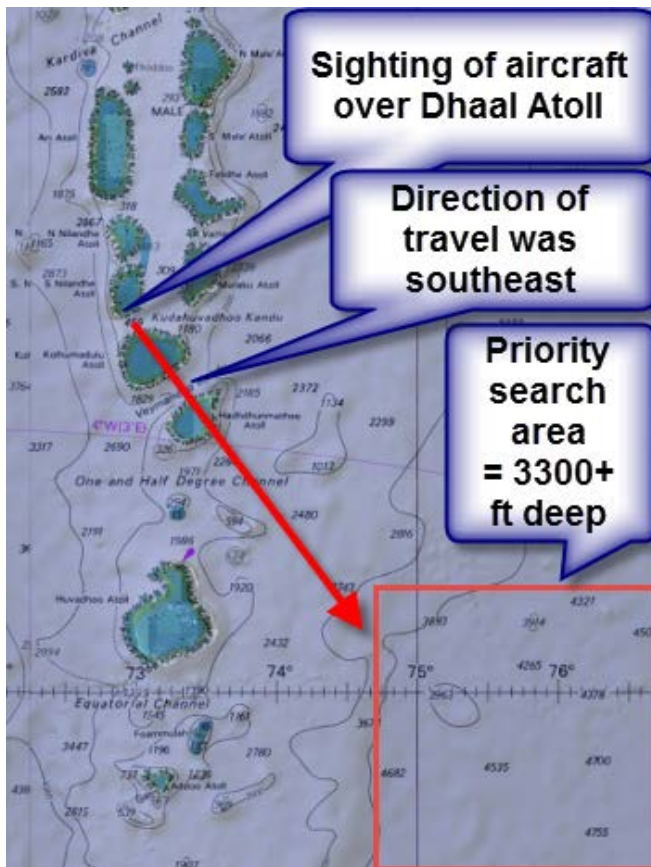


Figure 6. Priority search area southeast of Dhaal atoll in Maldives.



Over \$100 million has been expended on a fruitless search of the ocean off of the western coast of Australia. However, it appears that INMARSAT and ATSB have adopted an incorrect assumption, have refused to consider the possibility that this assumption is incorrect, and have persisted in misdirecting an enormous amount of public resources in the wrong direction. The analysis presented here suggests how this may have happened and implies lessons about the importance of checking and re-checking key assumptions before accepting conclusions derived from complex analyses conducted by specialists.

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Note: Source material for this report is available at <https://app.box.com/s/jbfrbkpwcuq7uf8apjxp>

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