SOME COMMENTS, QUESTIONS AND ANSWERS REGARDING MH370 (RELATED TO THE RECENT WORK BY G. CHEN ET AL.)

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Opening Statement

Regarding our paper:

[*] *G. Chen, C. Gu, P.J. Morris, E.G. Paterson, A. Sergeev, Y.-C. Wang and T. Wierzbicki, Malaysia Airlines Flight MH370: water entry of an airliner, 62(2015), 330–344, April 2015 issue of the Notices of The American Mathematical Society, Providence, RI,*

It was not stated clearly in the paper that this is only the first article in a sequence. The second one addressing the issue of break-up and fragmentation is in preparation. As in any scientific studies, various degrees of idealizations and simplifications are made in [*]. Therefore, it is still premature to make any statements based on the hydrodynamic analysis alone. However, such a solution gives a much needed distribution of pressures and forces acting on the fuselage in the initial stage of the water entry. So [*] sets a stage for the full analysis of the water impact problem and will then be used for the structural/failure analysis in the paper to follow.

Discussions of Raised Issues

Two months after the publication of our article [*], the work has caught media attention. We have received quite a few e-mails, especially to me, the first author of the article. The mystery surrounding the disappearance of MH370 remains one of the greatest in the aviation history, and the public interest continues at an all time high worldwide. We empathize with surviving family members and a global society that wants answers. While we appreciate the interest in our work as well as value the inputs of suggestions and criticisms from the many e-mail writers, there are key issues to be clarified lest they should be misinterpreted or become misleading. In addition, coverage made by a number of international

media outlets, in their overly enthusiastic news reports, has clearly overstated our results and claims without giving the proper contexts. My coauthors and I myself are not comfortable with any implied hype. The purpose of this blog is to clarify what I regard as some of the important issues and technical details.

There are a great many technical problems involved in the flying of a large aircraft and in the investigation of its crash. Therefore, under the constraints of time resources and technical competence, I can only single out the following questions on a short notice for clarification. I am fortunate to have the kind discussion and assistance of two technical and aviation experts, Michael Exner, retired CEO of Radiometrics, and Dr. Victor Iannello, CEO of Radiant Physics, as participants of this blog.

Q1: Has our work [*] determined (or "proved") that vertical water entry of MH370 (totally) explains the lack of floating debris and oil slick?

G. Chen: The answer is no. The main interest in [*] by our team is mathematical modeling and computation. Among the various scenarios of water-entry of MH370, see for example the 5 cases computed and simulated in [*], the *90° angle of entry*, with speed about 130 mph, still *is the one to have the least likelihood to break up*. It would have mainly *compressive* force acting on the fuselage. The locations on the body of the aircraft suffering the largest pressure and stress are the nose cone area and the wings leading edge, according to our numerical simulations. The wings would easily break off. The magnitude of local pressure in the nose cone area, which is about 35 to 40 times of the atmospheric pressure at the largest for *vertical entry* during the first few milliseconds after the aircraft hits water, can be seen in Figure 1. This pressure could cause fracture in the nose cone area, a *local failure*. This local fracture could grow to become *rupture* of the nose cone and cockpit area of the airliner. But the fuselage is on its way downward, which could partially block ("cap") the leakage of debris, things like personal effects, flight log journals, etc. If we examine the stress or pressure loading on the fuselage, it is usually not much larger than that on the nose cone. Thus, I expect mostly, small local failures of fracture on the fuselage.

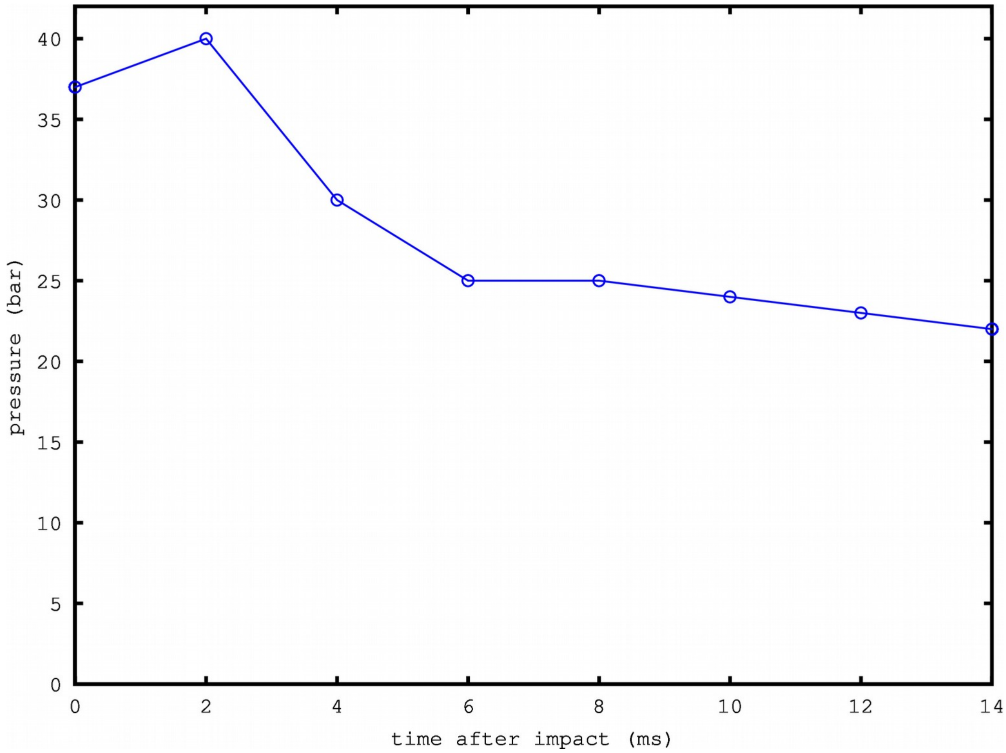
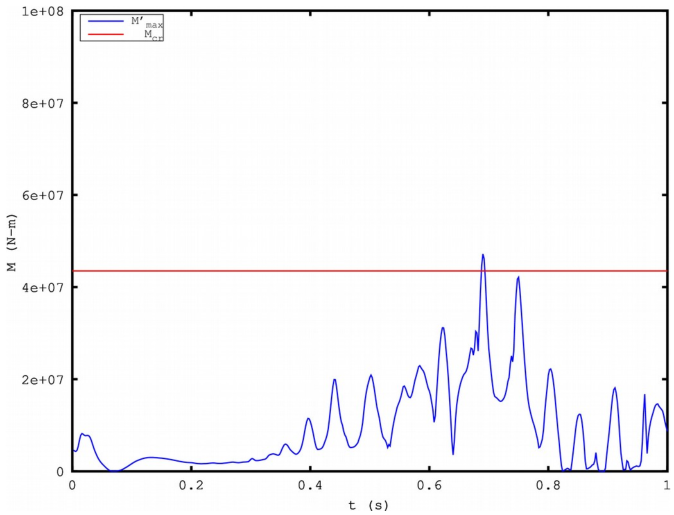


Figure 1: Time History of pressure loading on the tip of the nose-cone in vertical water entry (pitch angle=-90°) for a Boeing 777 airliner with a speed of 130 mph.

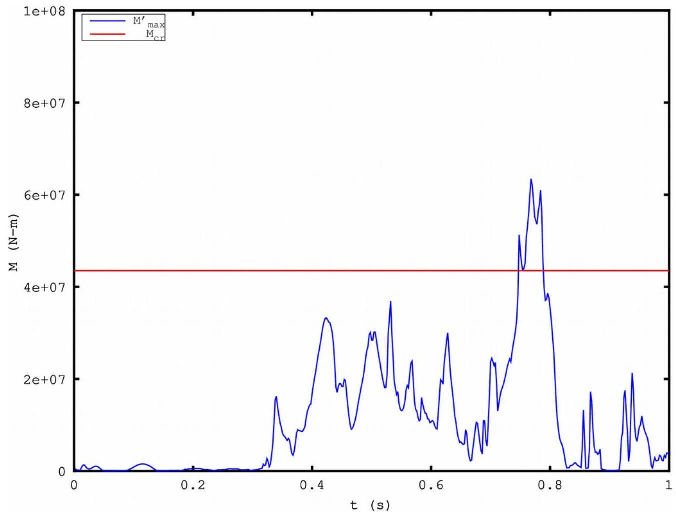
Q2: (Victor Iannello) You predict a fracture failure mode due to shear and tensile cracks at the ring supports near the cockpit that initiate locally but can progress globally and cause the rupture of the fuselage and wings for a vertical entry speed of 22 m/s (43 kn). Certainly the vertical speed greatly exceeded this value for a near vertical entry into the water, resulting in a global failure of the structure. Therefore, wouldn't MH370 have experienced a global structural failure with a near vertical entry?

G. C.: We assumed that the local shear failure at the cockpit does not progress globally, although this needs additional validation, and this mode could cause global failure as you indicate. Our assumption is valid only if the local failure is not large, and any leakage outward of the cockpit is "capped" by the descending aircraft. On the other hand, we assumed that the *large scale leakage of debris* that floats would occur from *global failures* that break up the fuselage into multiple segments due to global *bending moments* acting on the fuselage. Here,

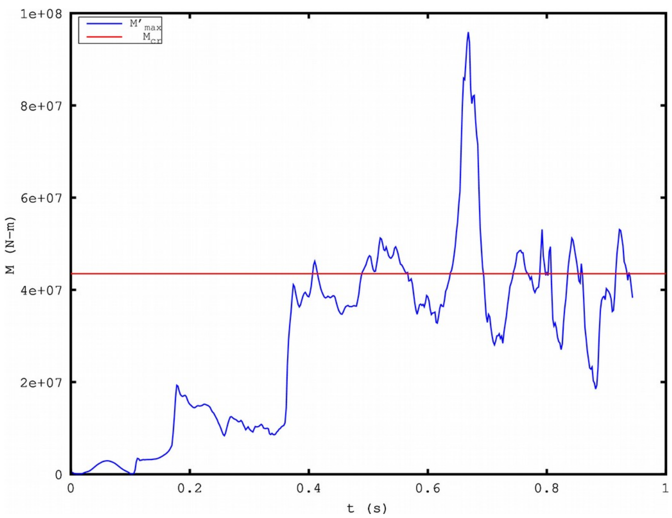
we have computed and parametrized the time-history of the largest values of bending moment distribution across the fuselage, for the 4 scenarios of different angles of water entry (pitch angle = 8°, -3°, -30°, -90°), we see that the angles of 8° and -90° have the smallest bending moment, equal to roughly one-half of the 30° angle of water entry, and about 2/3 of the bending moment of that of the -3°. But we have already ruled out the case of 8° pitch angle of water entry as it would likely cause *near-surface break up* due to the swells or tall waves on the open ocean.



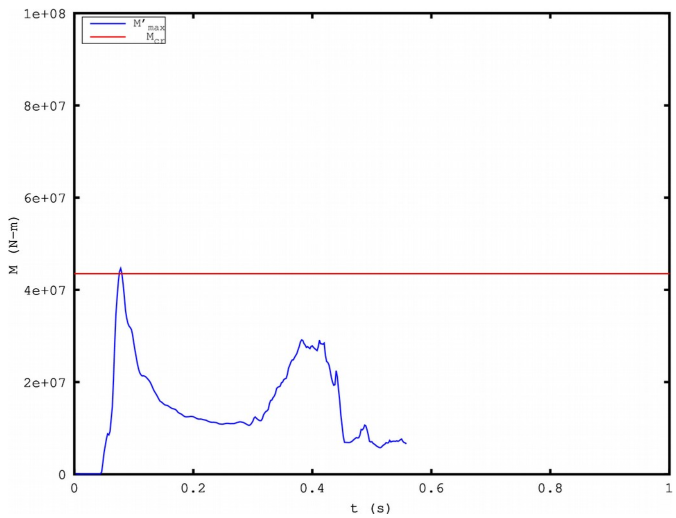
(a): Maximum effective bending moment for the scenario with 8° pitch angle.



(b): Maximum effective bending moment for the scenario with -3° pitch angle.



(c): Maximum effective bending moment for the scenario with -30° pitch angle.



(d): Maximum effective bending moment for the scenario with -90° pitch angle.

Fgure 2: Time History of maximum bending moment on the fuselage for, respectively, pitch angles 8°, -3°, -30° and -90°, at terminal velocity 130 mph. Note that the values of (d) are the smallest, predicting the reduced likelihood of fuselage break up (global failure).

Q3: (V. I.) You claim that because the surface pressure reached 6 MPa and the yield strength of aluminum is 324 MPa, there was no local failure of the aluminum. In truth, the surface pressure and the tensile stresses in the aluminum are far from equal! Wierzbicki and Yue (1986), for instance, found that a surface pressure of 1.2 MPa resulted in local tearing as the aluminum skin was elongated between the support rings to failure. Do you believe that the skin of a B777 can survive a surface pressure of 6 MPa = 60 atm = 880 psi?

G. C.: You are correct that high surface pressures will locally cause tearing of the aluminum skin. However, we have assumed that this failure does not progress globally and please note that *local failures produce mainly a small debris field, which could quickly disperse in the ocean.* This assumption needs to be further validated, of course.

Mike Exner: Your numerical simulation of the vertical entry is mostly based on the assumption of a slow velocity, at about 130mph at impact. However, it is well known that at high entry speed, which is more consistent with a likely *spiral descent*, the speed would be much higher, possibly even supersonic. Then the aircraft would “fracture” into small pieces because the water surface acts like a stone wall to the aircraft, just like what has happened to the recent Germanwings' crash.

G. C.: You are absolutely right that if the velocity at impact is suffciently high at water entry, any aircraft will suffer serious global failures and break up, regardless of angles of entry. Such breakups generally produce a large floating debris field that stays afloat for a long time. However, the key point here is that so far little or no floating debris has been observed or recovered. This essentially rules out the possibility of high speed water entry. Note: I am trying to do forensics here.

Summary: The CFD simulations have certain advantages in predicting aircraft failure. Here the attention of our work in [*] is helpful in predicting local and global failures, but *only at the near take-off or landing speed* around 130mph. More simulations at much higher speeds are needed in order to compare their bending moments for the prediction of fuselage break up and global failures. For example, we have heard from an experienced military aircraft pilot (with pseudoname Twiggy) saying that he/she witnessed the wreckage of a crashed fighter jet that looked like a "mess of metal clump" when it was recovered from

the deep ocean. Obviously, with a large water-entry speed, any aircraft will break up (and generate floating debris) regardless of what the pitch angles are. But we essentially need to rule out a high speed water entry.

Q4: (V. I.)d The paper [*] did not analytically address the buckling failure of the thin cylindrical shell. It only acknowledges that this failure mode can occur at low impact velocities based on NASA experiments with a true aircraft. Wierzbicki and Yue (1986) in their analysis of the Space Shuttle also acknowledge that this mode may occur at lower impact speeds than for the other modes considered, but partially justified ignoring this mode because of the presence of the tiles on the skin of the Shuttle. Obviously, there are no tiles on the skin of a B777. Can you answer the effects of buckling?

G.C.: At lower velocities of vertical water entry such as the case in [*], the compressive force acting on along the fuselage axis may not yet be significant , because the "beam" (as a structural analog for the fuselage) has both ends as "free". However, if the fuselage is modeled as a hollow shell as you suggest, then such a nonlinear buckling effect will have an early onset as far as velocities are concerned. So, ultimately, when the speed is medium and not low, such buckling effect must be taken into account. I think it should still be correct that bending (global) failure take place

Q5: (G.C.) This question was raised by a reader of [*]. If the airliner did sink onto the bottom of the ocean and remained intact, wouldn't it be crushed by deep water pressure there, causing an implosion and then leaking all of the light debris upward to the ocean surface?

M.E.: Most likely, this won't happen. On its way sinking down, the airliner will take up water through the structural failure spots and, therefore, will not be air-tight, intact on the bottom of the ocean floor and presumably causing an implosion and leakage of debris.

Q6: Is the nose-dive speed of 130 mph viable for a Boeing 777 airliner?

M.E.: A low speed on the order of 130 mph is *incompatible* with a near vertical flight. The aircraft would accelerate very rapidly (near 1 g) if pointed straight

down. Thus the vertical simulations (over only a short distance for the aircraft) in the paper are *not yet realistic* for entry speed. The minimum viable such speed must be re-estimated.

Overall Summary

Previous studies on the disappearance of MH370 has focused mainly on the *flight path determination* by satellite data analysis. (Inmarsat's analytics now has been mostly accepted as correct.) The work in [*] has started *the first study* of numerical simulations of the crash of an airliner into water. However, the field of impact engineering, flight mechanics, fluid dynamics, and avionics that are needed in the study of aircraft crash is *highly interdisciplinary* and requires a large team to perform research. One of the main findings in [*], namely, *vertical water entry being the final trajectory of MH370 could be accepted mainly under the assumptions of relatively medium to low speed upon water-entry that leads to local failures that don't progress globally, and, therefore, should not be taken too literally as universal and true at all speeds.* Further CFD simulations and impact/failure analysis based on the parametrizations of important factors such as terminal velocity, altitude and pitch angle should further improve our understanding of what can and has happened to a crashed aircraft.

On the other hand, the lack of a large floating debris field rules out the possibility of a high velocity water entry.

G. Chen says it would be both inaccurate and irresponsible for him or any of his co-authors to speculate outside the scope of their research. They can offer only a plausible, science-based theory as to the absence of a typical debris field and fuel residue that the public has come to expect with aviation accidents. The *beauty* of this, however, is that *scientifically based forensics* can still be deduced based on the fact that there is a *total absence of evidence* (such as floating debris and oil slick).

To reiterate, some media coverage has overstated their findings and claims without providing proper context. G. Chen urges extra cautions for both journalists and the general public to avoid the temptation to sensationalize or extrapolate beyond the team’s results and expertise.