THE LAST SECONDS OF FLIGHT OF THE TU-154M IN SMOLENSK ON 10TH OF APRIL 2010

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Abstract

Trajectories have been found based on the CFD data calculated using a precise 3D model of the TU-154M in landing configuration and using validated state of the art software by an independent and highly professional company working within the aviation industry performing CFD computation for companies like Boeing. The results presented at the previous Smolensk Conference are confirmed. The Polish QAR black box data and distinct areas of vegetation damage located before and after the Bodin birch tree clearly support the hypothesis of additional wing loss. The aerodynamic work shows, that the plane would not have crashed if only the wing tip of 5.5m was lost, and that the plane was likely to be 60 to 75 m above the height of runway 26 (RWY26) at the entrance of the middle marker zone when doing a go-around (aborted landing approach) inside the middle marker zone. This corresponds to a calculated height above the RWY26 of 95m to 100m at the time 10:40:50.5 where the pilots according to the official Russian investigation by radio called they would initiate their go-around. In other words this is in full agreement with what to expect from the crew given the decision height for this approach was 100 m and thereby confirming the results presented in this work and supporting the pilots handled the approach in a correct manner. The go-around was suddenly aborted by first the loss of the 5.5 m wing tip followed by another effectively 4.5 m wing loss 120 m closer to the crash site. The latter loss made the crash unavoidable and the plane hit the ground with about 22m/s vertical speed. A study of the damages seen on the left root structure together with the ground trace studies point towards the breakage of the fuselage and wings caused by high internal fuselage pressure about 0.3 s after the initial wing-ground contact. This also explains why all ground traces suddenly stop and no crater is formed despite the 78.6 ton plane was claimed by the Russians to have hit the soft ground resulting in more than 100 g (or an equivalent of 78600 ton).

Keywords* - *CFD, Wing Damage, Roll, Smolensk, TU-154.

Streszczenie

W oparciu o wyniki obliczeń CFD wykonanych przy użyciu precyzyjnego modelu 3D samolotu Tu-154 w konfiguracji jak przy lądowaniu znaleziono trajektorie samolotu. W obliczeniach zastosowano zwalidowane najnowsze oprogramowanie stosowane przez niezależne i wysoce profesjonalne firmy działające w dziedzinie obliczeń CFD dla firm takich jak Boeing. Zostały potwierdzone wyniki obliczeń przedstawione na poprzedniej Konferencji Smoleńskiej. Dane z polskiej czarnej skrzynki QAR oraz wyraźne uszkodzenia roślinności zlokalizowane zarówno przed jak i za brzozą Bodina, wyraźnie potwierdzają hipotezę o dodatkowej utracie skrzydła. Analiza aerodynamiczna pokazuje, że samolot nie uległby rozbiciu, jeśli utraciłby jedynie końcówkę skrzydła o długości 5,5 m i że samolot był od 60 do 75 m powyżej pasa startowego robiąc odejście, gdy mijał środkowy marker. Opowiada to obliczeniowej wysokości od 95 m do 100 m powyżej RWY26, wtedy gdy 10:40:50.5 piloci, według oficjalnego rosyjskiego dochodzenia, oświadczyli przez radio, że rozpoczynają odejście. Innymi słowy, jest to w pełni zgodne z tym, czego należało oczekiwać od załogi znajdującej się na wysokości decyzji, która dla tego podejścia wynosiła 100 m i tym samym, jest zgodne z wynikami przedstawionymi w tej pracy, a także potwierdza, że piloci wykonywali podejście w sposób poprawny. Odejście zostało nagle przerwane przez pierwszą utratę 5,5 m kocówki skrzydła, po której nastąpiła utrata dalszych efektywnych 4,5 m skrzydła, gdy samolot był 120 m bliżej miejsca katastrofy. Ta druga utrata doprowadziła do katastrofy nie do uniknięcia i samolot uderzył w grunt z prędkością pionową około 22 m/s. Uszkodzenia widoczne na korpusie lewego skrzydła wraz z analizą śladów na ziemi wskazują na zniszczenie kadłuba i skrzydeł spowodowane przez wysokie wewnętrzne ciśnienie w kadłubie około 0,3 s po początkowym kontakcie skrzydła z gruntem. To wyjaśnia również, dlaczego znikły naglewszystkie ślady na gruncie i nie powstał żaden krater, mimo że jak twierdzą Rosjanie, ważący 78,6 t samolot musiał uderzyć w miękki grunt z przyspieszeniem większym niż 100 g (lub ekwiwalentną siłą 78600 ton).

Słowa kluczowe* – *CFD, uszkodzenie skrzydła, beczka samolotu, Smoleńsk, TU-154.

1. INTRODUCTION

For the first time trajectories of the final seconds of flight are based on CFD data generated solely through a *representative* model of the TU-154M for the case of a wing loss of 5.5m of the left wing [1]. In previous studies [2, 3] the work and conclusions were based on a highly inaccurate model of the TU-154 presented in [2]. In [4]the author has documented how the main model errors in [2] all lead to the same *effect of pushing more lift towards the tip*. The work presented in part 1 of this paper [3] was based on the CFD work of [2] corrected for the main errors as described in [4]. The work presented here is solely based on [1]. The main conclusions are the same as earlier:

The plane flew well above the birch tree said to have cut the left wing tip of the plane. The loss of only the 5.5m wing tip would not cause the plane to crash.

2. MODEL DESCRIPTION

The present model takes the lifting forces and moments of roll found in [1] as input data for the various cases: Lost length (0 m, 5.5 m, 10 m) with and without pilot interaction (by full right aileron and full right outer interceptor).

The detailed model description can be found in [3].

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3. RESULTS

3.1. Trajectories

With a total mass of M_{tot} = 78.600kg [5] and a vertical acceleration as recorded by the planes flight data recorders of *G* = 1.3 [5] the required lifting force in Z direction can be written

$$F_z = M_{tot} * g * G, \tag{1}$$

where *g* is the gravitational acceleration g = 9.81m/s^2, thus

$$F_z = 1002kN \tag{2}$$

In order to create this lift force the overall lifting coefficient Cl needed to be

$$Cl_z = \frac{F_z}{\frac{1}{2} * S * \rho_{air} * V_{plane}^{\ 2}}, \tag{3}$$

$$Cl_z = 1.516, \tag{4}$$

where ρ_{air} =1.272kg/m^3 is the air density, S is the wing reference area (S = 180 m^2 [5]), and V_{plane} = 76 m/s the plane velocity. From [6] and [1] the overall lifting coefficient as a function of the angle of attack (AOA or α) is known.

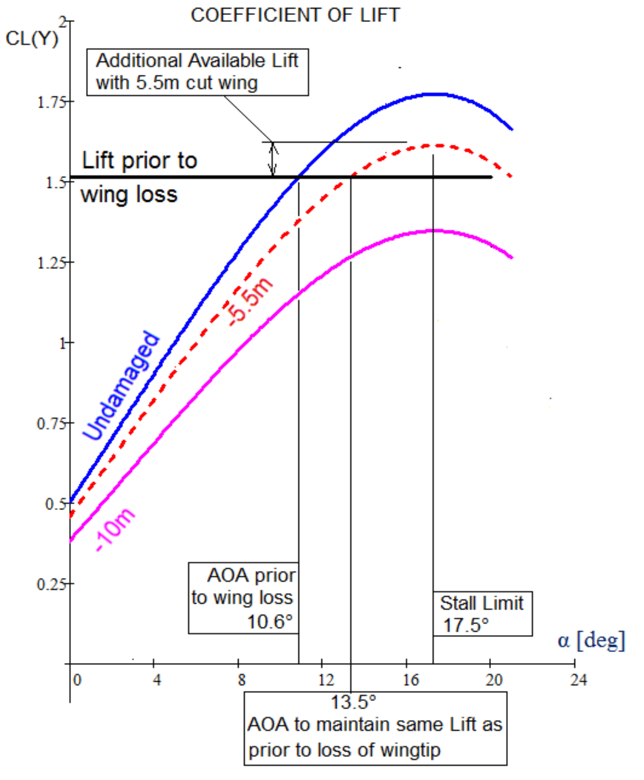

Fig. 1. The overall lifting coefficient Cl versus the angle of attack for the undamaged wing (blue solid line), a wing with a loss of ΔL=5.5 m (red dashed line) and a wing with loss of ΔL=10 m (magenta solid line).

By Fig. 1 it is seen, that a lifting coefficient of Cl = 1.516 is obtained for α = 10.6° for the undamaged wing and for α = 13.5° for the case of a loss of a wing span of ΔL = 5.5 m.

In other words the pilots could without stalling pull more lift to entirely compensate for the wing loss of ΔL = 5.5 m and even continue the upwards acceleration they had begun before the wing tip of was removed. If they at the same time wanted to compensate for the moderate roll caused by the asymmetric wing, they could do so, but would need to slightly decrease the upwards acceleration from G = 1.3 to say G = 1.25 [5]. In this case they would be able to climb about 38 m between the birch tree and crash site and they could keep the planes roll angle between 20° to 30°, as shown in Fig. 2 depending on how quickly they react.

3.2. Wing damaged by at least two events

Based on the vertical acceleration signal from the MAK report, the hypothesis was put forward in [7], that the wing was damaged by (at least) two events. The first removing the left wing tip of 5.5 m and the second 47 m further downstream removing an additional about 5 m of the left wing. The present work based on the CFD data of [1] clearly supports this hypothesis of additional wing loss by two or more events. Further support is achieved by analyzing the amplitude of the recorded vertical acceleration signal. The signal from the Polish QAR data recorder is shown in Fig. 3, and according to this the second loss of wing area happens about 120 m after the first loss of wing tip.

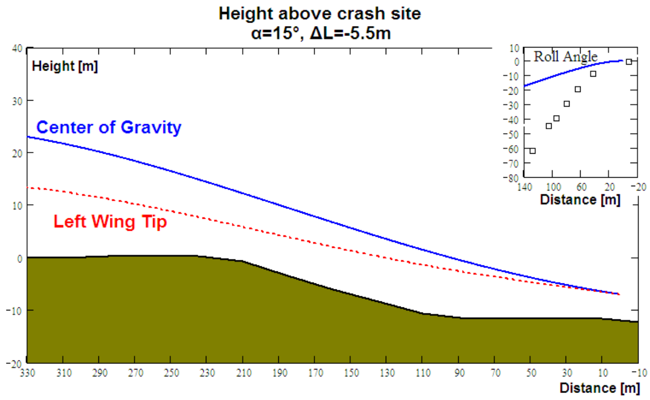

Fig. 2. The calculated trajectory of the planes center of gravity (blue line) and left wing tip (red dotted line) for the case of a wing loss of ΔL=5.5 m at 5 m height above the ground of the birch tree as assumed by the official Russian story. Here with the use of the right aileron/outer interceptor. The effect of the immediate vertical velocity change of ΔVz= -2 m/s as found in equation (6) is included. The plane is flying from right to left. The green area represents the ground height as by [5]. The small inserted box shows the resulting roll angle of the plane (blue line) together with the recorded roll angle (black squares). Note the plane would roll moderately and climb well above the crash site with a loss of the wing tip only. Note the roll angle of the plane after 140 m flight (see inserted box in upper right corner) corresponds well with the recorded plane roll by the QAR black box (roll = 17°) as shown in Fig. 3.

Note this is a sampled signal with a relative course sampling frequency, but still allowing a rough estimate of the lost lifting power causing the sudden drop in vertical acceleration. When a portion of the wing is suddenly removed, the lifting power will drop instantly. The result of this being, that a vertical downwards acceleration is superimposed to the planes initial motion. This downwards acceleration will have the effect of increasing the angle of attack and thereby again increase the lifting power of the plane on expense of the planes height. Many people have experienced this, maybe without noticing it, when the plane they are flying goes through an "air hole".

The change in vertical velocity for an acceleration of ΔG_1 over the time ΔT_1 can be found as

$$\Delta V_{z1} = g * \Delta G_1 * \Delta T_1, \tag{5}$$

where ΔG_1 is the sudden drop in vertical acceleration, and ΔT the time this occurs. For a drop of say ΔG_1 = 0.367 over at time say ΔT_1 = 0.6 s (see Fig. 3) one gets

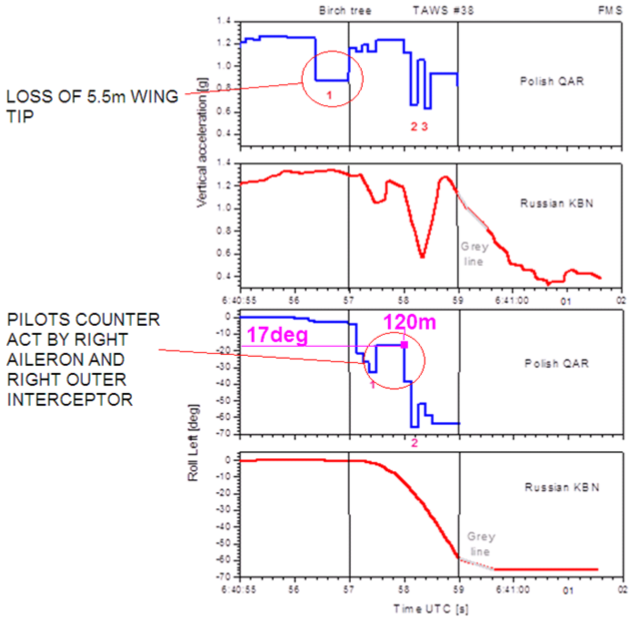

Fig. 3. From the top is shown the vertical acceleration by the Polish QAR, then the same by the Russian KBN. Next two plots show the left roll angle by the Polish QAR then the same by the Russian KBN. Event 1 corresponds to the loss of the wing tip and event (2, 3) the loss of the additional effective 4.5 m of the left wing. The distance from first drop in the vertical acceleration signal to the second event is approximately 120 m by the QAR data and about 47m by the Russian KBN data. The roll of the plane 120m after loosing the wing tip can be seen as ϕ= -17° by the black box data. This agrees well with the calculated value shown in fig. 2 Original figure by Prof. Kazimierz Nowaczyk.

$$\Delta V_{z1} = 9.81 m/s^2 * 0.367 * 0.6 s = 2.16 m/s \,. \qquad (6)$$

Such imposed vertical velocity will result in a change in the angle of attack $\Delta\alpha_1$, which can be found as

$$\Delta\alpha_1 = a\tan(\Delta V_{z1} / V_{plane}) \qquad (7)$$

or

$$\Delta\alpha_1 = a\tan(2.16/76) = 1.63^o \qquad (8)$$

for an initial forward plane speed of V_{plane} = 76 m/s.

Such change in angle of attack corresponds to a certain change in the overall lifting coefficient, which can be estimated as

$$\Delta Cl(\Delta\alpha_1) \;= CL(\alpha_0 + \Delta\alpha_1) - CL(\alpha_0) \,, \qquad (9)$$

where α_0 = 10.6° is the initial angle of attack prior to the wing loss. Taking values from Fig. 1, one gets

$$\Delta Cl(\Delta\alpha_1) \;= 1.627 - 1.516 = 0.112 \;. \qquad (10)$$

To the first order the relative change in lifting power (R_1) associated with the first drop in vertical acceleration can be found as

$$R_1 \;= \Delta Cl(\Delta\alpha_1)/Cl(\alpha_0) = 0.112/1.516 = 7.4\% \,. \qquad (11)$$

In a similar way the relative change in lifting power associated with the second drop can be found, here taking into account the roll angle of the plane:

$$\Delta V_{z2} = 9.81 m/s^2 * 0.6 * 0.41 s / \cos(20^0) \,, \qquad (12)$$

$$\Delta V_{z2} = 2.63 m/s \,, \qquad (13)$$

$$\Delta\alpha_2 = a\tan(2.63/76) = 2^o \,, \qquad (14)$$

$$\Delta Cl(\Delta\alpha_2) \;= (CL(\alpha_{02} + \Delta\alpha_2) - CL(\alpha_{02})) * 0.91 \,, \qquad (15)$$

$$\Delta Cl(\Delta\alpha_2) \;= (1.625 - 1.494) * 0.91 = 0.119 \,, \qquad (16)$$

where α_{02} is the new angle of attack prior to the second loss of wing area, and can be approximated as

$$\Delta\alpha_{02} = \alpha_0 + \Delta\alpha_1 = 12.23^0 \,. \qquad (17)$$

From Fig. 1 the lifting coefficient values are found and the relative change in lifting power associated with the second loss of wing area R_2 is found as

$$R_2 \;= \Delta Cl(\Delta\alpha_2)/(Cl(\alpha_{02}) * 0.91) \qquad (18)$$

$$R_2 \;= 0.119/1.359 = 9\% \qquad (19)$$

Roughly bringing the total wing loss to about 16 %. Note this is not intended to be a highly precise calculation of the loss, such would require higher sampling rate and a detailed integration. Taking the course sampling and the simple method of estimation into account both contributions are in the order of the value found by the CFD analysis.

With other words the two significant drops in the recorded vertical acceleration signal correlate reasonably with the two events, first loss of the wing tip and then secondly an additional loss of 4.5 m wing area.

3.3. Roll angle after loss of wing tip

In the event a sudden impact causes the plane to start rolling about its length axis, any pilot will immediately by instinct counter act to maintain the desired wing position in particular when the plane is close to the ground. This is comparable to the bicycle rider, whom is hit from the side by a sudden wind gust. He automatically reacts to keep the bicycle in the correct position ad avoiding the accident. Of course there will in both cases be a certain human reaction time and system latency. Assuming the reaction time and system latency of ΔT=0.3 s the planes roll angle can be found to ϕ = -17° as shown in Fig. 4. This correlates well with the data from the Polish QAR (see Fig. 3), where the roll angle just after the loss of the wing tip first changes to ϕ = -32°, then back to ϕ = -17° after the pilot interaction and just prior to the second loss of wing area

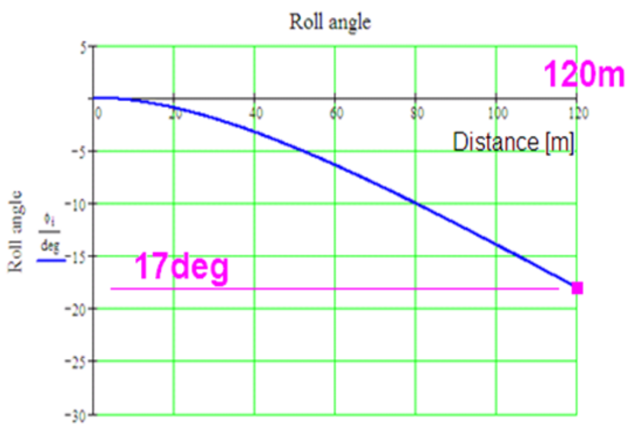

Fig. 4. The calculated roll angle as a function of distance in the event the reaction time of ΔT=0.3 s to achieve the full right aileron and full right outer interceptor between the two wing losses. This takes into account the human reaction time and the system latency. The roll angle in this case is found to be ϕ = -17° at a distance 120 m from the loss of the wing tip. This corresponds very well with the value recorded by the QAR black box as shown in Fig. 3.

3.4. Trajectories

The areo dynamical calculations show the major wing loss needed to take place at a distance prior to the birch tree depending on the height of the plane in order for this to reach the crash site. The higher the plane the earlier the wing cut needed be initiated. Calculations show the plane would hit the area free of buildings south of runway 26 if the pilots as expected and guided by the tower kept the plane within the lower and upper glidepaths. The middle marker (MM) is the final point where the pilots must decide wether to continue the landing approach or do a go-around depending wether they have visual sight of the runway or not (see Fig. 6 and Fig. 7)..

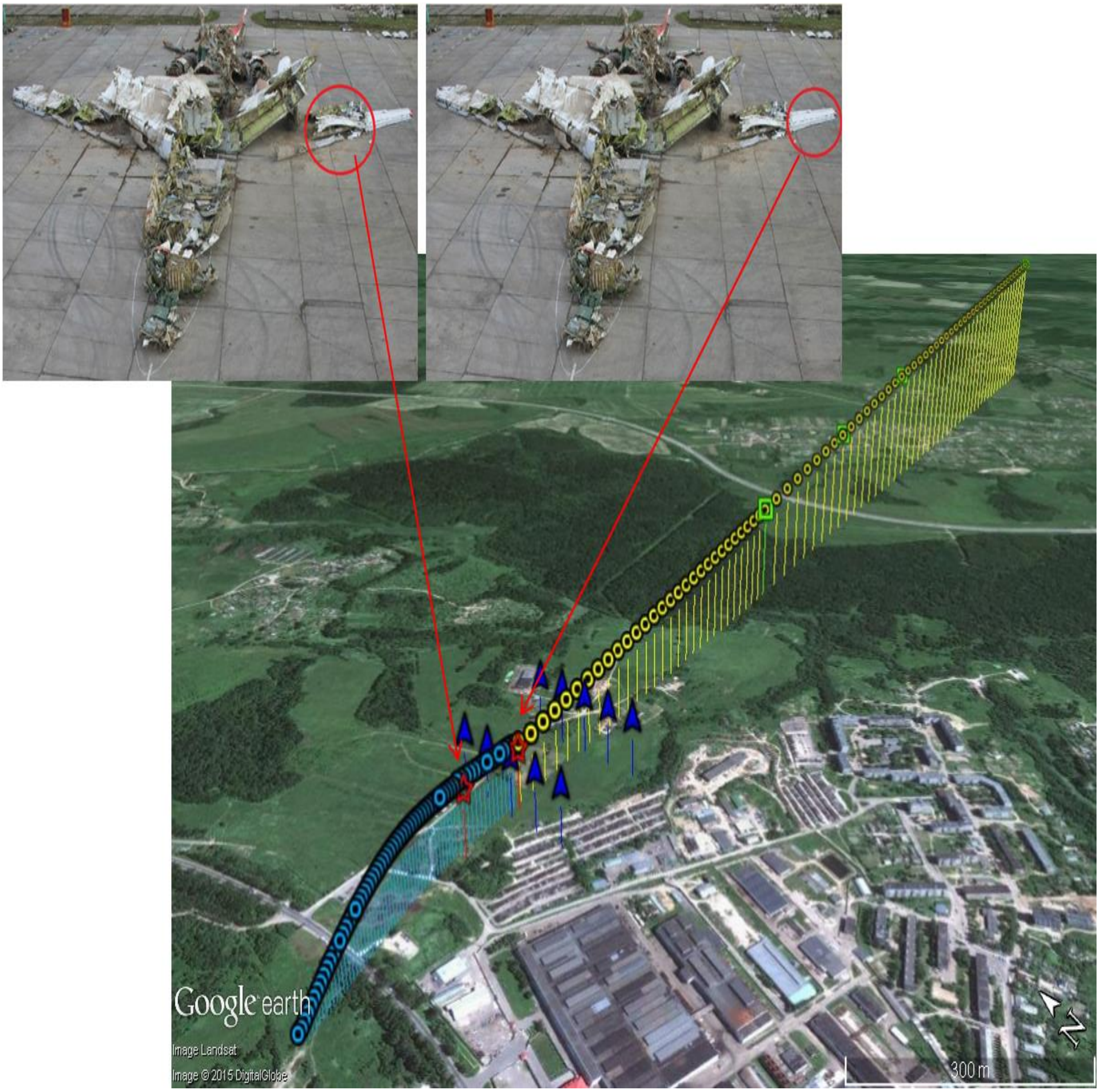

Fig. 5. The green squares show the logged GPS heights [8, 9] and positions of the TAWS 34 to TAWS 37 events [8, 9], and the yellow dots show the trajectory line between these together with the trajectory of go-around within the middle marker zone (blue triangles). Working back from the crash site by the aerodynamics brings the trajectory of the center of gravity (blue circles) to the exact position of the GPS trajectory. According to the official Russian explaination the pilots called they would do "go-around" at T=10:40:50.5. The calculated height above runway 26 at this point is H=95m to H=100m. This confirms the calculations, as H=100m is the official decision height during this approach. With other words this is the lowest height, where the pilots must make their decision to either continue the approach or perform a go-around depending on wether they have correct visual sight of the runway or not. By the official explaination it is known, that the pilots did not have the required visual sight of the runway, and it is therefore a logic consequence of this, that they called the go-around at this height. The data and calculations clearly support this. The red stars show the two positions where the wing explosions occured, and the upper figures show which wing sections are lost. The second explosion mainly removes the top part of the middle wing section by creating a center hole. During the remaining flight this part of the wing continues to break up as a result of the aerodynamic forces. The bottom part of the middle section with the Polish emblem is most likely torn off during the first wing ground contact. Following the two wing explosions a third explosion emptying the center fuel tanks toke place at the position of the TAWS 38 , and was probably the cause of the false interpretation by the control system that the plane had landed

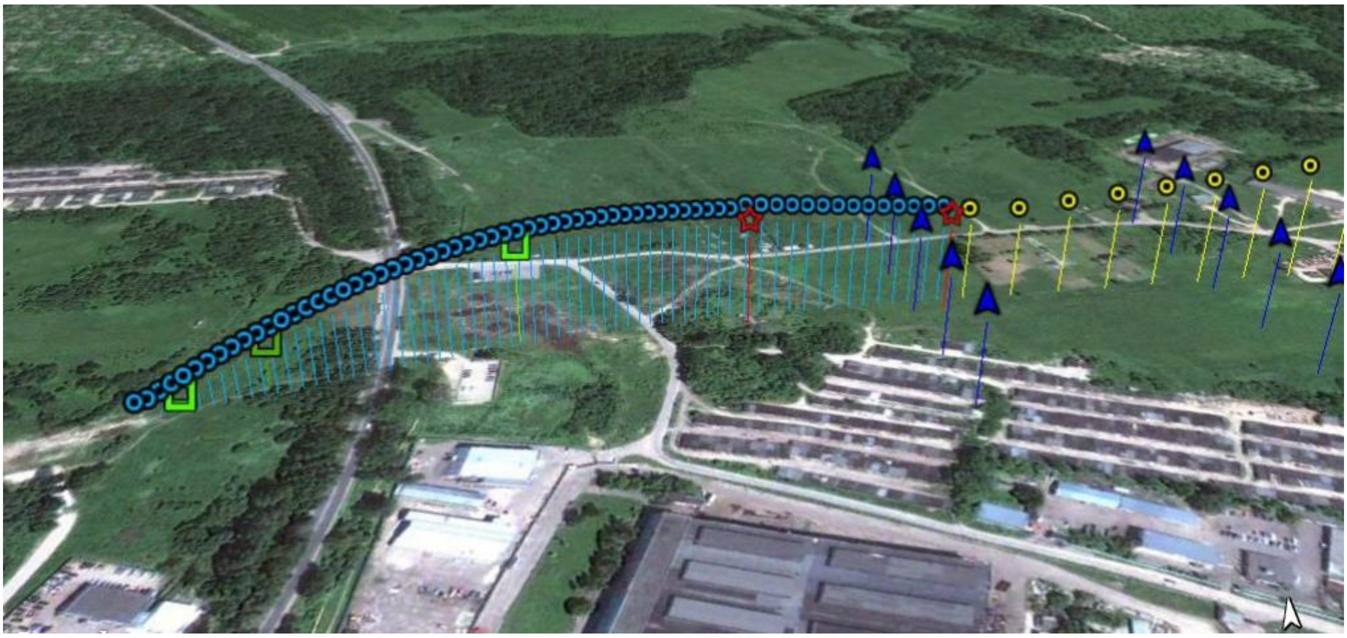

Fig. 6. The loss of the wing tip occurs during pulling up in the go-around just prior to exiting the middle marker zone shown between the blue triangles at a height of about 55 m. The height entering the middle marker zone is about 75 m. The calculated trajectory of the center of gravity of the plane agrees reasonably with the logged GPS height of the TAWS 38 (the calculated height is slightly higher than the logged) and fits well with the baro corrected height and GPS position stored by the FMS (green squares). The velocity towards the ground at this point is recorded as Vz=22.2 m/s and agrees very well with the calculated Vz=23 m/s.

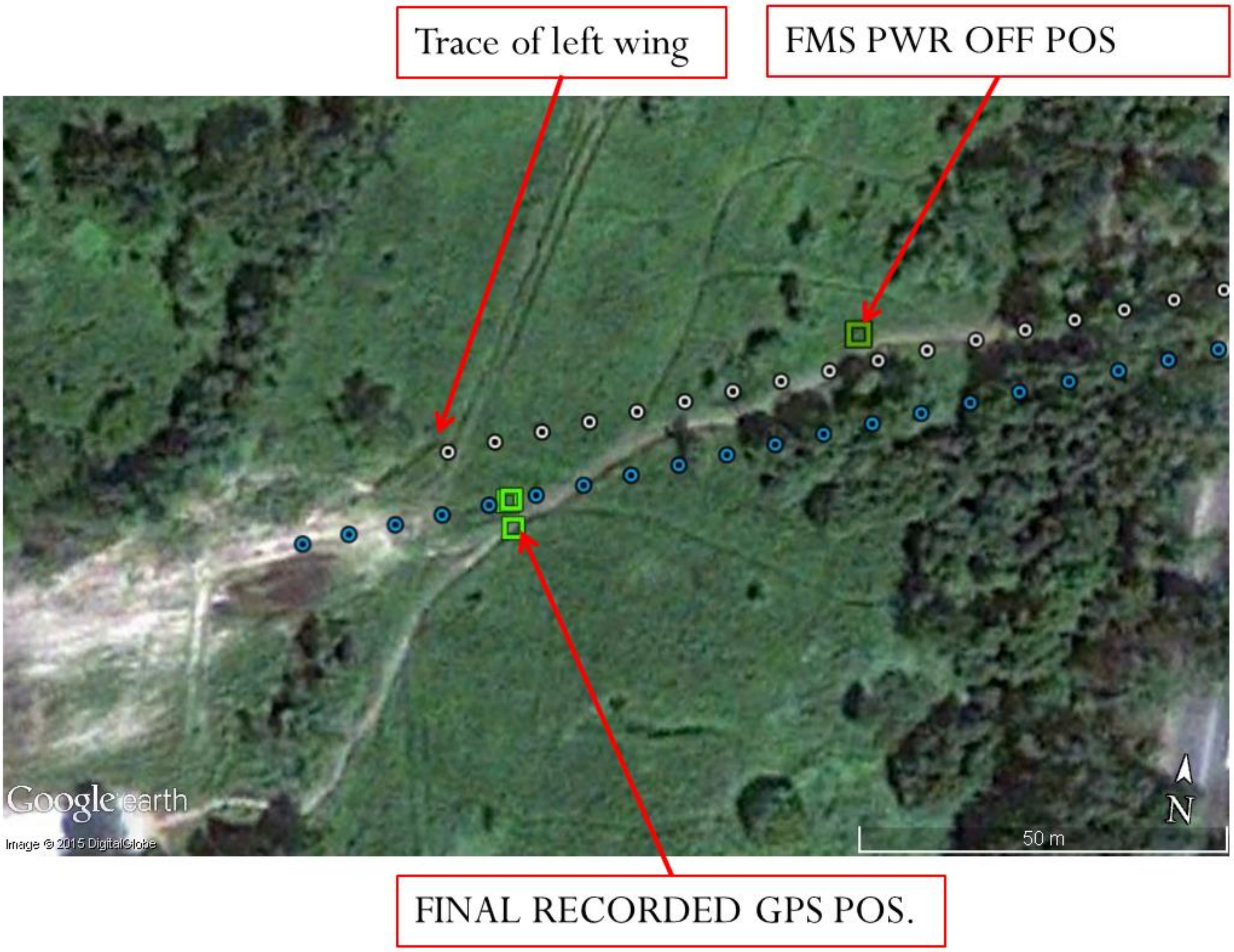

Fig. 7. The calculated trajectory of the center of gravity (COG) of the plane (blue circles) and the calculated trajectory of the left wing (white circles). Note how the wing trajectory ends at the position of the wing ground trace, and how the COG trajectory ends at the correct location passing through the final recorded three independent GPS positions. Note also how the heading is in well agreement with the direction of the ground scratches.

A decision height [10] is a specified height in the precision approach at which a missed approach must be initiated if the required visual reference, such as the runway or runway environment, to continue the approach has not been acquired. This allows the pilot sufficient time to safely re-configure the aircraft to climb and execute the missed approach procedures while avoiding terrain and obstacles. For ICAO CAT I landings the minimum decision height is 60 m [11] and for this landing field 72 m [5], for the aircraft and crew the decision height was stated to be 100m [5]. The decision height during approach will always be the highest of the individual heights for the airfield, pilot and plane, i.e. 100m for this approach at Smolensk.

Fig. 5 shows how the calculated trajectory based on the aero dynamics and the CFD input perfectly meet the trajectory made by a line passing through the recorded GPS heights and positions including a go-around manuvure as recorded by the vertical acceleration sensor. Also the calculated vertical speed towards the ground is in agreement with the recorded 22.2 m/s at the position of the final FMS recording 60 m before the point of wing ground contact. With other words *the pilots never made the very strange steep dive to the ground 2-3 km before runway 26 as claimed by the Russians.* They did not approach terrain with 23 m/s when at 65 m above the ground as stated in the MAK report. Such dive makes no sense what so ever, even assuming the pilots experienced a "clash of motives" as stated in the MAK report. The GPS positions measured by the three independent GPS units and the radio height variations told the pilots exactly where they were above terrain, and trying to land 1 km short of the runway in total fog is not logic and not explained on this background. The fact the 1st pilot set his altimeter to standard pressure (QNH = 1013.25 mb) during the final approach could describe that *he was preparing for the fase following the planned go-around, namely climbing through the transition level when re-directing to the alternative airfield.* Assuming that he should be mislead by this change in pressure setting he according to the Russian official story himself had deliberatly made just seconds earlier seems very unlikely and a statement badly invented for the occasion. Badly because not even this fits with the russian trajectory, as the corresponding height change as a result of such change in pressure setting is about ΔH =175 m and not the ΔH=60 m the russians claim. The altimeter is the basic tool for any pilot and he is well trained to use this. It is very unlikely a commercial pilot would ever make such mistake of interpretation, and in this case even monitored by the 2nd pilot and navigator. In addition the navigator is constantly reading the radio heights throughout the cabin, so the crew would immediately detect any mismatch of altitude.

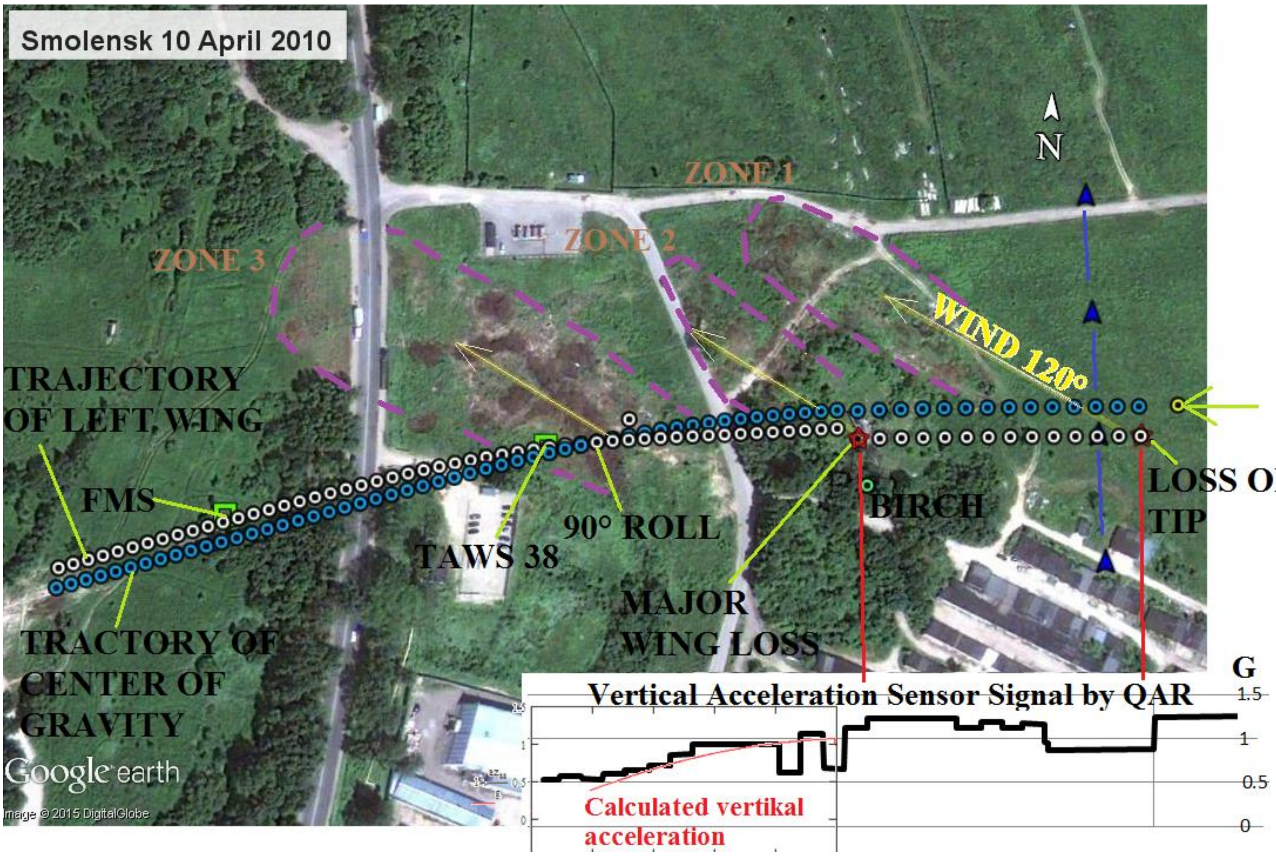

Fig. 8. The calculated trajectory for the center of gravity (blue) and the left wing tip (white). The satellite picture is from the 25th of June 2010 (two months after the crash). Notice the distinct and significant damage of vegetation in the three areas (zone 1, zone 2 and zone 3) circled by the dashed lines. Adding the recorded vertical acceleration signal by the Polish QAR (black line) and the wind direction of 120° show the clear correlation between the three distinct areas of vegetation damage to the approximate positions of the loss of the wing tip, loss of additional wing area and a third explosion emptying the center fuel tanks and triggering the TAWS 38 recording. In agreement with the location of the damaged vegetation patterns the loss of the wing tip toke place 100m - 120 m earlier than the birch tree just before or after the exit of the middle marker zone (blue triangles). The distance between the patterns corresponds to the flying distance between the two events (loss of wing lift) as recorded by the Polish QAR black box. The final calculated velocity (Vz=23 m/s) towards the ground at the "FMS" point agrees well with the recorded value of Vz=22.2 m/s. The scenario can also explain why wing parts are found earlier than the birch tree and in a belt along the highway north of the trajectory. The calculated vertical acceleration (red line of bottom fig.) shows same characteristic decline as the recorded signal..

The calculated roll angle for the case of additional effective 4.5 m wing loss fits very well with the recorded roll angles as shown in [3]. From Fig. 15 three distinct areas of vegetation damage are seen. The map is taken on the 25th of June 2010 just two months after the crash. The distance between the first two in the direction of flight is about 100m to 120 m, which correlates very well with the distance the plane flew between the significant drops in vertical acceleration (loss of wing area) as recorded by the Polish QAR data recorder.

Fig. 9. The front bottom section below the president's salon. The entire top section is pulverized and the window section was thrown outwards most likely caused by the high internal pressure at the near ground explosion. Note the windows have not been in ground contact.

Fig. 10. The left wing root shortly after the crash. The portion shown in the pictures left side was originally facing towards the fuselage. Notice the wheels are soiled on the inwards side of both rows, but not along the entire rim, only at the small portion of the rim, that was facing downwards during the sideways sliding/turning movement of the wing piece. Also notice the end of the wheel house shows indication of being hit by an object (most likely a tree) from the wings topside during the roll movement described below

The damaged vegetation (see zone 1 and zone 2 of Fig. 8 fits with fuel/hydraulic oil poisoning of the vegetation by the fuel and hydraulic oil dispersed from the planes wing at each wing loss and carried by the 120° wind. The third and largest zone (zone 3 of Fig. 8) of damaged vegetation occurred down wind from the region the planes roll angle passed through 90° at the position of TAWS 38.

Normally the control system will detect a landing event as the moment when the wheels are pushed towards the wings rather than hanging by their own weight. A plane rotated 90° or more will experience much higher sensitivity towards mechanical disturbences as the gravitational force is not pulling the wheels away from the wing. The position and size and shape of the third damaged zone of vegetation points towards a sudden release of a releative large amount of fuel.

Assuming some scattering of the dispersed fuel due to the wake surrounding the plane, the width of zone 3 of about 50m suggests a fuel release with less than 0.4s. This fact and knowing the two earlier zones were caused by such sudden events leads to the conclusion the third zone was the result of the sudden release caused by a third explosion. The false detected "landed" event at the point of TAWS38 agrees with this hypothesis as a result of the mechanical disturbance associated with the explosion when the plane roll made the landed detection system sensitive for such disturbances. The calculated wing trajectory ends at the position of the wing ground trace as shown in Fig. 7, and the center of gravity ends at the correct location passing through the final recorded three independent GPS positions. These field data thereby support the calculated trajectories.Fig. 7 shows also that the heading is in well agreement with the direction of the ground scratches.

The scenario also explains why wing parts are found earlier than the birch tree. The calculated vertical acceleration (red line of bottom Fig. 15) shows same characteristic decline as the recorded signal, and the results are again confirmed by field data.

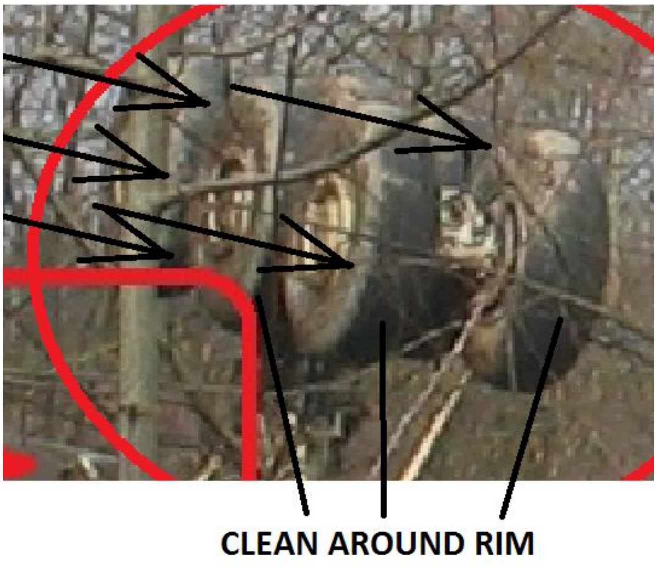

Fig. 11. The *inwards* side of the both rows of the left wheels is soiled, whereas the rims themselves are clean. Had the wheels been downwards in a normal landing position and making contact with the soft ground at the crash site, the rims should be covered with mud all around.

3.5. First ground contact

A 3D analysis of the planes initial ground contact was described in [3]. The ground traces can be shown to fit *only* with the TU-154M with a 10m shortened left wing experiencing a left roll of about 120°. A closer look at the left wheels show these have clean wheel rims, but soiled wheel sides. This goes for both rows of wheels, as shown in Fig. 14 and Fig. 15. This can be explained by the movement of the left root wing structure in an outwards movement as the plane crashes to the ground (see Fig. 16).

Fig. 12. Same as Fig. 11.

A high internal pressure is the most likely explanation for such outwards movement with this clockwise rotation (as seen from behind), because the turning moment arising from the downwards movement of the fuselage would result in an opposite rotation of this structure, due to the left wing tip making ground contact (see Fig. 17). The high internal pressure of the explosion changes the anti clockwise rotation of the wing root sending this outwards in a clockwise rotation (see Fig. 18).

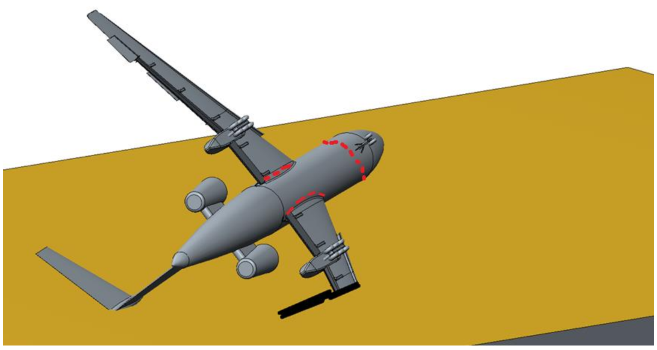

Fig. 13. The plane making its first ground contact with the left wing tip and tail. The planes orientation is found both by the aero dynamical work and independently confirmed by the ground trace analysis [3]. As the left wing tip is in contact with the ground the downwards movement of the fuselage will result in an anti clockwise rotation of the left root part.

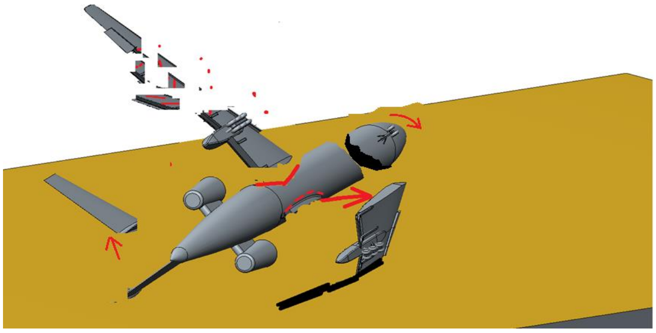

Fig. 14. Based on the length of the ground trace the first main fuselage explosion occurred 0.3 s after the initial ground contact. From this point all ground traces suddenly stop, and no crater is formed even though the official explaination states the 78.6 tonne plane hit the soft ground with more than 100 g, equal to 78600 tonne [5].

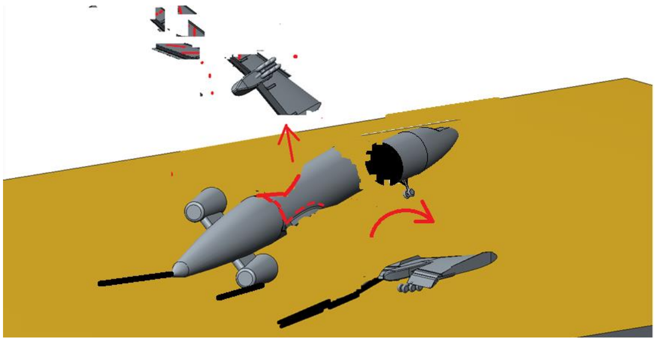

Fig. 15. When the wheels hit the ground and continued the outwards sliding movement superimposed on the intial forward velocity of the plane, the inner sides of the wheels scrapped against the ground and were soiled on this side and the inner rim portion that was downward during the slide.

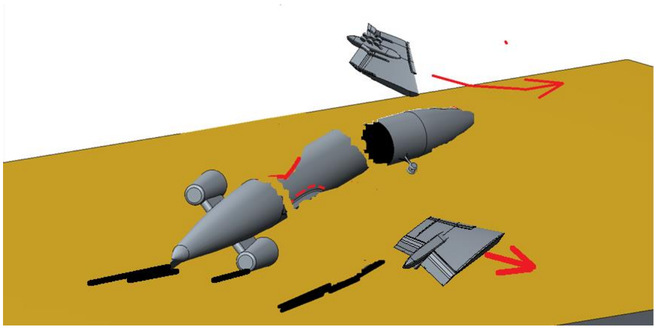

Fig. 16. The root part continues its sideways movement and rotation.

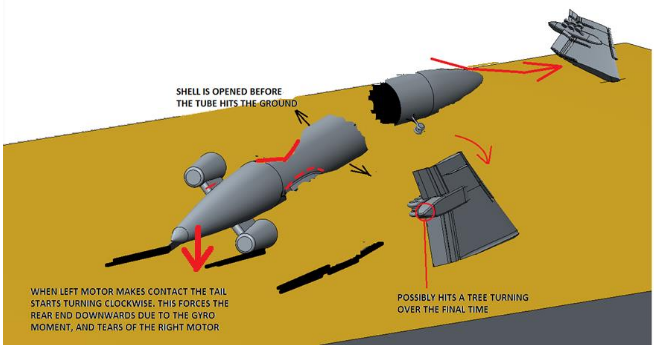

Fig. 17. During the rotation the left wheel house hits an obstacle (probably a tree) and damages the wheel house tip partly cutting this. Note the fuselage is still in free air when the explosion occurs, allowing this to open and the sides to be move outwards prior to it hitting the ground.

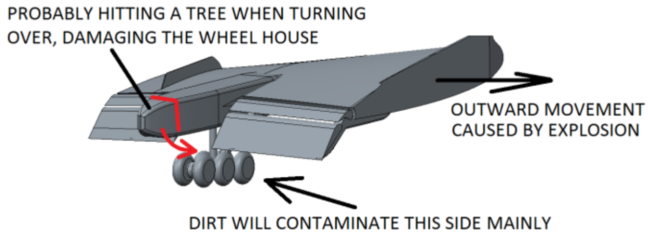

Fig. 18. The outwards sliding movement caused by the fuselage explosion will tend to contaminate the inner sides of the left wheels and the portion of the wheel rims facing downwards. The wheels show no sign of rotation during this movement.

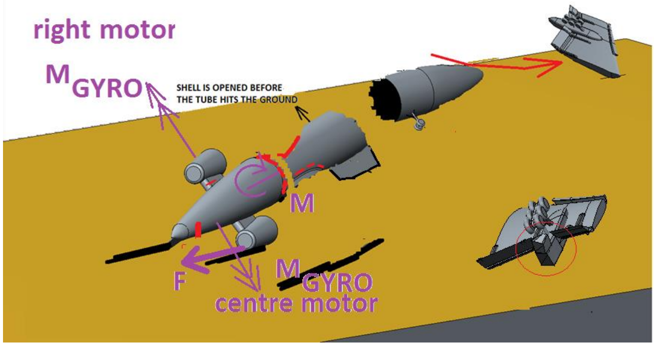

Fig. 19. The drag force imposed on the left motor as it plungers into the ground results in a turning moment M of the tail section. This causes the gyro moment of the right motor to try to twist the tail sections front part downwards, while the center motor tries to do the opposite. When the gyro moment exceeds the strength of the right motor support, the center gyro motor is allowed to quickly rotate the tail section so the front end of the tail now goes up, thereby damaging the tail rear.

When the wheels hit the ground and continued the outwards sliding movement superimposed on the initial forward velocity of the plane, the inner sides of the wheels scrap against the ground and are soiled on this side and the inner rim portion that was downward during the slide (see Fig. 16 to Fig. 18). During the rotation the left wheel house hits an obstacle (probably a tree) and damages the wheel house tip partly cutting this, and this resulting in the damage of the wheel hous as shown in Fig. 10. Note the fuselage will at this time still be in free air when the explosion occurs, allowing this to open and the sides to be moved outwards prior to it hitting the ground. As the cockpit seperates from the body due to inertia it continues its rotation and ends with the front wheels down as they will block for the further rotation. This can explain why the front section has a near to normal orientation compared to the rest of the plane.The drag force imposed on the left motor as it plungers into the ground results in a turning moment M of the tail section (see Fig. 19). This again causes the gyro moment of the right motor to tend to twist the tail sections front part downwards, while the center motor tends to do the opposite. When the gyro moment exceeds the strength of the right motor support, the center gyro motor is allowed to quickly rotate the tail section so the front end of the tail now goes up, thereby damaging the back part of the tail (see Fig. 20). The inner structure of the tail shows clear sign of being bent by the gyro moment of the right motor (see Fig. 21).

This indicates the tail structure was separated from the rest of the fuselage structure while the gyro moment was acting. The front bottom section below the president's salon is shown in Fig. 9. The entire top section is pulverized and missing. The window section was thrown outwards like caused by a high internal pressure at the near ground explosion. The windows show no sign of being in ground contact, which excludes the possibility of the top side of the fuselage being damaged and torn during the ground contact itself.

Fig. 20. The back part of the tail was damaged by the centre motors gyro moment when the right motor broke off.

Fig. 21. The tail fuselage shows sign of the struggling between the gyro moments of the centre motor and right motor. Also notice the structure is twisted downwards inside the fuselage, indicating this structure was seperated from the rest of the fuselage at the time of impact.

4. Conclusion

The CFD data calculated using a precise 3D model of the TU-154M in landing configuration and state of the art validated software by an independent and highly professional company working within the field of CFD computation for companies like Boeing [7] provides input for the aero dynamical calculations presented in this work.

The aero dynamical calculations show:

1. The TU-154M plane would not crash if only the wing tip of 5.5 m was lost at the claimed birch tree location in 5 m height above the ground.
2. The black box data and vegetation damage correlate well with the theory of additional wing loss, loosing

first the 5.5 m wing tip followed by an additional effective 4.5 m wing 120 m after the first loss.

3. The calculated roll angle counteraction by the pilot's instinct act by activation of the right aileron and right outer interceptor correlate very well with the recorded values by the Polish QAR flight recorder, when allowing for a latency of 0.3s reaction time.
4. The pilots had no chance to avoid a crash after the additional loss of wing length of another about 4.5 m effective length occurring 120 m after the loss of the wing tip.
5. The speed of roll correlates well with the recorded values.
6. The final roll angle correlates well with the value found by a ground trace analysis [3] and reported by [5].
7. The pilots push the right leg as the plane rotates 90° in an effort to gain height.
8. The pilots push the steering colum (normally equal to nose down) during the final flight, which agrees with the plane being upside down.
9. The calculated final vertical speed towards the ground is around 23m/s, and this agrees well with black box recordings at the "FMS" point of 22.2 m/s.

Calculations show the plane would hit the area free of buildings south of runway 26 if the pilots as expected and guided by the tower kept the plane within the lower and upper glidepaths.

The recorded vertical acceleration data by the Polish QAR is shown to correlate with the predicted amount of wing loss by the two events thereby supporting the hypothesis of first loss of the wing tip and 120 m further downstream loss of an additional effective 4.5 m of the left wing.

The calculated height above the RWY26 at the time 10:40:50.5 where the pilots according to the official Russian investigation by radio called they would initiate their go-around is found as H = 95m to 100m. In other words this is in full agreement with regulations and the flight manual given the decision height for this approach was 100 m and thereby confirming the results presented in this work and supporting the pilots handled the approach in a correct manner.

The three distinct damaged areas of vegetation as seen on the arial photo of the 25th of June 2010 a couple of months after the crash correlate well with the expected location of wing losses (zone 1 and zone 2 of Fig. 8) when taking the direction of wind of 120° into account. Zone 3 is by far the largest zone of damaged vegetation, and the width and shape of this suggests a third explosion releasing a significant amount of fuel while the plane had about 90° rotation. The rotation of the plane increases the sensitivety of the landing sensor located at the wheels, and can explain why the TAWS 38 recording was triggered due to mechanical disturbances caused by the third explosion.

The twisted structure inside the tail fuselage indicates the tail was separated from the rest of the plane in air prior to the fuselage and left motor making ground contact.

The soil contamination on the inner side of the left wheels and the damage of the wheel house point towards a high internal pressure occurring 0.3 s after the time the left wing makes its initial ground contact. This high pressure occurs while the fuselage is still in air just meters above the ground and separates the wing root from the fuselage, sending this outwards with a rotation. The time of the near ground explosion is based on the length of the ground trace of the left wing, and can explain why all ground traces suddenly stop and why no crater is found despite the official explanation declares the 78.6 ton plane met the soft ground with more than 100 g or 78600 ton. It also explains how one hand from one victim was found nearly 1m deep into the ground in the area where the tail hit the ground.

5. CONCLUDING REMARKS

The analyzed data strongly support the pilots initiated the go-around when they called this at about H=100m height above runway 26 at the time claimed in the official report (10:40:50.5). About 100m to 120 m before the birch tree and just prior to leaving the middle marker zone the plane lost first the wing tip and then an additional effective 4.5 m wing at a height of about 58m above the ground of the RWY26. The third explosion occurred another 100m from the second wing explosion, and released a major portion of the remaining fuel in less than 0.5s. Close to ground the tail of the plane was seperated in free air from the rest of the plane shortly followed by a series of parallel explosions inside the fuselage designed to kill people on board. *This would be in agreement with the pilots calling a go-around at 100m as of the black box voice recordings, the zones of damaged vegetation, the final velocity towards the ground, the measured GPS positions, the logic and normal approach, the approach as recorded by the TAWS GPS heights and positions, the finding of wing parts prior to the birch tree and hanging loosely on the birch tree, the calculated vertical acceleration, the recorded FMS height and position, the calculated horizontal trajectory, the final heading of the plane, the position of the TAWS 38 event triggered by a "landed" signal, the erroneous behaviour of the left and right elevator signals following the second wing explosion, the finding of a human hand about 1m into the ground and finally the wing trajectory and ground traces.* The aero dynamical work is verified against the recorded data and geographical observations. The observations and data very different in nature clearly support the hypothesis.

6. ACKNOWLEDGMENTS

The CFD work was strongly supported by Metacomp Technologies Inc., to whom I am very great full. Metacomp technologies Inc. has a large experience within the field of CFD analysis. They work together with several major aircraft industries using Metacomp's validated state of the art software CFD++. I would also like to acknowledge Senior Mech. Eng. Jan Andrzejewski Professor Kazimierz Nowaczyk and Professor Wieslaw Binienda for on going support and technical discussions.

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